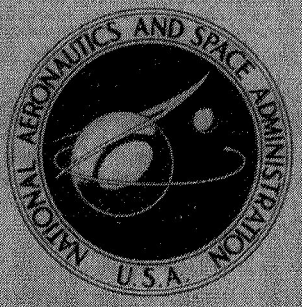
NASA TECHNICAL MEMORANDUM



NASA TM X-2041

NASA TM X-2041

A COMPUTER PROGRAM TO DETERMINE EQUILIBRIUM-AIR FLOW-FIELD DATA ABOUT A BLUNT BODY BY THE METHOD OF INTEGRAL RELATIONS

by Frances W. Taylor

Langley Research Center
Hampton, Va. 23365

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1970

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM X-2041		

4. Title and Subtitle	5. Report Date
A COMPUTER PROGRAM TO DETERMINE EQUILIBRIUM-AIR FLOW-FIELD DATA ABOUT A BLUNT BODY BY THE METHOD OF INTEGRAL RELATIONS	June 1970
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Frances W. Taylor	L-7071
	10. Work Unit No.
	125-23-04-04
9. Performing Organization Name and Address	11. Contract or Grant No.
NASA Langley Research Center Hampton, Va. 23365	
	13. Type of Report and Period Covered
	Technical Memorandum
12. Sponsoring Agency Name and Address	14. Sponsoring Agency Code
National Aeronautics and Space Administration Washington, D.C. 20546	

15. Supplementary Notes

16. Abstract

A computer program (program D1251) has been developed in support of the study of the inviscid, adiabatic flow properties (pressure, temperature, density, velocities, and enthalpy) around a blunt body in equilibrium air by use of a modified method of integral relations. This report describes the digital computer program including the methods used in the digital approximation, flow charts, D1251 program code, instructions for the user, and a test case with input and output listings.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Equilibrium air Blunt-body flow fields Integral-relations solutions	Unclassified – Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	79	$3.00

*For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151

CONTENTS

A COMPUTER PROGRAM TO DETERMINE EQUILIBRIUM-AIR FLOW-FIELD DATA ABOUT A BLUNT BODY BY THE METHOD OF INTEGRAL RELATIONS

By Frances W. Taylor
Langley Research Center

SUMMARY

A computer program (program D1251) has been developed in support of the study of the inviscid, adiabatic flow properties (pressure, temperature, density, velocities, and enthalpy) around a blunt body in equilibrium air by use of a modified method of integral relations. This report describes the digital computer program including the methods used in the digital approximation, flow charts, D1251 program code, instructions for the user, and a test case with input and output listings.

INTRODUCTION

Reference 1 presents a modified approach to the first-order approximation in the method of integral relations for the numerical calculation of the inviscid, adiabatic, subsonic flow field about a blunt-nose body traveling at hypersonic speeds. Solutions were obtained and computed flow-field data were presented for the adiabatic steady flow of air in chemical equilibrium. A computer program (program D1251) was developed to evaluate the feasibility of this approach. Results obtained in reference 1 agree with results from inverse and property-derivative integral-relations techniques and experiment. The agreement indicates that this relatively simple method of solution provides an accurate description of the blunt-body flow field in the subsonic region.

A description of the computer program for equilibrium air is presented herein along with the methods used in the digital approximation, flow charts, program code, instructions for the user, and a test case with input and output listings.

SYMBOLS

A_j coefficients in governing differential equations

a_0 tangential velocity gradient at the body surface

B_j coefficients in governing differential equations

C coefficients in governing differential equations

E_j coefficients in governing differential equations

G_j functions appearing in the governing partial differential equations which are differentiated with respect to y

h static enthalpy

H total enthalpy, $h + \frac{u^2 + v^2}{2}$

I_j functions appearing in the governing partial differential equations which are differentiated with respect to x

p pressure

Q curvature of the body, $\frac{R_B}{R_b}$

R' universal gas constant

r radius measured from axis of symmetry of body (see fig. 1)

r_b normal distance from axis of symmetry to a point on the body (see fig. 1)

R_B body radius of curvature at $x = 0$

R_b local body radius of curvature (see fig. 1)

T' temperature, ^oK

U'_∞ free-stream velocity, cm/sec

u,v velocity components in the x- and y-direction, respectively

V_R resultant velocity

$\overline{W}_{REF}$ molecular weight of cold air, 28.96 g/mole

x	coordinate along the body surface (see fig. 1)
y	coordinate normal to the body surface (see fig. 1)
Z	compressibility
z	axial coordinate (see fig. 1)
γ	ratio of specific heats
δ	shock displacement distance (see fig. 1)
δ_o	value of shock displacement distance at axis of symmetry
η	transformed y-coordinate, y/δ
θ_b	body inclination angle (see fig. 1)
ρ	density
ω	shock-wave angle (see fig. 1)

Subscripts:

j	used (as first subscript) to denote a particular governing differential equation:
	1 shock-geometry equation
	2 continuity equation
	3 x-momentum equation
	4 y-momentum equation
	5 energy equation
s	shock-oriented properties
η	denotes location within shock layer:
	0 body surface
	1 at shock wave
∞	free-stream conditions

When double subscripts are used, the first (j) denotes the governing equation number and the second (η) denotes location within shock layer, that is, 0 for conditions at body surface and 1 for conditions at shock wave.

Primes denote dimensional quantities.

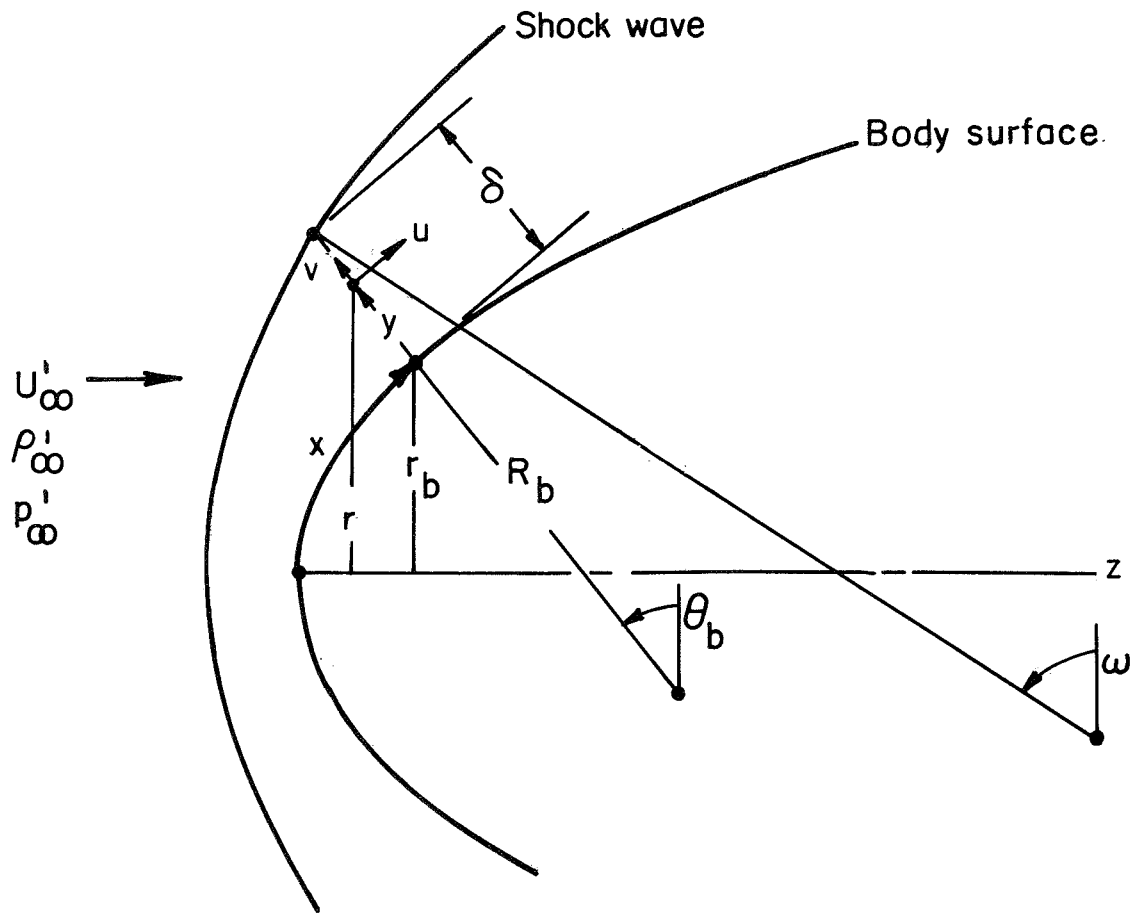


Figure 1.- Flow-field coordinate system.

PROBLEM DESCRIPTION

The equations which govern inviscid, adiabatic steady flow of equilibrium air over a blunt body traveling at hypersonic speeds are a system of nonlinear partial differential equations derived from the laws of conservation of mass, momentum, and energy. The modified method of integral relations, as described in reference 1, is used to transform the governing equations into a set of ordinary differential equations that are numerically integrated to yield the details of the thermodynamic and flow properties within the shock layer. The ordinary differential equations which form the basis for the program D1251 are as follows:

$$\left.\begin{aligned}
\frac{d\delta}{dx} &= -E_1 = (1 + Q\delta)\tan(\omega - \theta_b) \\
\frac{d\omega}{dx} &= \frac{-A_4 \frac{d\delta}{dx} + E_4}{B_4} \\
\frac{dI_{2,0}}{dx} &= \frac{-A_2 \frac{d\delta}{dx} + B_2 \frac{d\omega}{dx} + E_2}{C} \\
\frac{dI_{3,0}}{dx} &= u_0 \frac{dI_{2,0}}{dx} \\
\frac{dI_{5,0}}{dx} &= \frac{-A_5 \frac{d\delta}{dx} + B_5 \frac{d\omega}{dx} + E_5}{C}
\end{aligned}\right\} \qquad (1)$$

The equations for the fluxes of mass, momentum (in the x-direction), and energy at the body surface are

$$\left.\begin{aligned}
I_{2,0} &= \rho_0 u_0 \\
I_{3,0} &= p_0 + \rho_0 u_0^2 \\
I_{5,0} &= \rho_0 u_0 H_0
\end{aligned}\right\} \qquad (2)$$

The quantities have been nondimensionalized as follows:

$$x = \frac{x'}{R'_B} \qquad \delta = \frac{\delta'}{R'_B} \qquad p = \frac{p'}{\rho'_\infty (U'_\infty)^2}$$

$$y = \frac{y'}{R'_B} \qquad \rho = \frac{\rho'}{\rho'_\infty} \qquad H = \frac{H'}{(U'_\infty)^2}$$

$$u = \frac{u'}{U'_\infty} \qquad R_b = \frac{R'_b}{R'_B} \qquad h = \frac{h'}{(U'_\infty)^2}$$

$$v = \frac{v'}{U'_\infty} \qquad r = \frac{r'}{R'_B}$$

where primes denote dimensional quantities.

The coefficients of the governing differential equations are developed in reference 1. The expressions for the coefficients are

$$A_2 = 3\left(I_{2,0} - I_{2,1}\right) + \frac{2\delta \cos \theta_b}{r_b}\left(I_{2,0} - I_{2,1}\right)$$

$$A_4 = -\left(3 + \frac{\delta \cos \theta_b}{r_b}\right) I_{4,1}$$

$$A_5 = 3\left(I_{5,0} - I_{5,1}\right) + \frac{2\delta \cos \theta_b}{r_b}\left(I_{5,0} - I_{5,1}\right)$$

$$B_j = \delta\left(3 + \frac{2\delta \cos \theta_b}{r_b}\right)\frac{\partial I_{j,1}}{\partial \omega} \qquad (j = 2,4,5)$$

$$C = \delta\left(3 + \frac{\delta \cos \theta_b}{r_b}\right)$$

$$E_1 = \frac{-(1 + Q\delta)}{Q} \tan\left(\omega - \theta_b\right)\frac{d\theta_b}{dx}$$

$$E_2 = \frac{3\delta}{r_b}\left(I_{2,0} + I_{2,1}\right)\frac{dr_b}{dx} + \delta\left(3 + \frac{2\delta \cos \theta_b}{r_b}\right)\frac{\partial I_{2,1}}{\partial \theta_b}\frac{d\theta_b}{dx}$$

$$- \frac{\delta^2 \sin \theta_b}{r_b}\left(I_{2,0} + 2I_{2,1}\right)\frac{d\theta_b}{dx} + 6(1 + \delta Q)\left(1 + \frac{\delta \cos \theta_b}{r_b}\right) G_{2,1}$$

$$E_4 = \frac{3\delta}{r_b} I_{4,1} \frac{dr_b}{dx} + \delta\left(3 + \frac{2\delta \cos \theta_b}{r_b}\right)\frac{\partial I_{4,1}}{\partial \theta_b}\frac{d\theta_b}{dx} - \frac{2\delta^2 \sin \theta_b}{r_b} I_{4,1} \frac{d\theta_b}{dx}$$

$$+ 6(1 + \delta Q)\left(1 + \frac{\delta \cos \theta_b}{r_b}\right) G_{4,1} - 6G_{4,0} - 3\left(\delta Q + \frac{\delta \cos \theta_b}{r_b}\right)\left(I_{3,0} + I_{3,1}\right)$$

$$- \frac{2\delta^2 Q \cos \theta_b}{r_b}\left(I_{3,0} + 2I_{3,1}\right) + \frac{3\delta \cos \theta_b}{r_b}\left(\rho_0 u_0^2 + \rho_1 u_1^2\right)$$

$$+ \frac{\delta^2 Q \cos \theta_b}{r_b}\left(\rho_0 u_0^2 + 2\rho_1 u_1^2\right)$$

$$E_5 = \frac{3\delta}{r_b}\left(I_{5,0} + I_{5,1}\right)\frac{dr_b}{dx} - \frac{\delta^2 \sin\theta_b}{r_b}\left(I_{5,0} + 2I_{5,1}\right)\frac{d\theta_b}{dx}$$

$$+ \delta\left(3 + \frac{2\delta\cos\theta_b}{r_b}\right)\frac{\partial I_{5,1}}{\partial\theta_b}\frac{d\theta_b}{dx} + 6\left(1 + \frac{\delta\cos\theta_b}{r_b}\right)(1 + \delta Q)G_{5,1} + 6R_F$$

where

$$G_{2,1} = \rho_1 v_1$$

$$G_{4,0} = p_0$$

$$G_{4,1} = p_1 + \rho_1 v_1$$

$$G_{5,1} = \rho_1 v_1 H_1$$

$$I_{2,0} = \rho_0 u_0$$

$$I_{2,1} = \rho_1 u_1$$

$$I_{3,0} = p_0 + \rho_0 u_0^2$$

$$I_{3,1} = p_1 + \rho_1 u_1^2$$

$$I_{4,0} = 0$$

$$I_{4,1} = \rho_1 u_1 v_1$$

$$I_{5,0} = \rho_0 u_0 H_0$$

$$I_{5,1} = \rho_1 u_1 H_1$$

Limited provision has been made in the governing equations for coupled radiating-flow-field analyses, but a radiation subprogram is not included in this program. Thus, the radiation flux term R_F is not programed.

The governing differential equations are solved by a fourth-order Runge-Kutta integration technique (see the appendix) to give shock-layer thickness, the shock angle, and the fluxes of mass, momentum, and energy at the body surface. The numerical integration proceeds from the stagnation point (x = 0); however, direct substitution of the initial values

into the governing differential equations at $x = 0$ results in indeterminate (0/0) expressions. (See ref. 1.) Application of L'Hospital's rule yields the proper starting values for the nonzero derivatives:

$$\frac{d\omega}{dx} = \frac{\left(3 + 3\delta_o + \delta_o^2\right)\left(p_0 - p_1 - \rho_1 v_1^2\right)}{\delta_o\left(3 + 2\delta_o\right)\rho_1 v_1 \frac{\partial u_1}{\partial \omega}}$$

$$\frac{dI_{2,0}}{dx} = -\frac{\delta_o\left(3 + 2\delta_o\right)\rho_1 \frac{\partial u_1}{\partial \omega}\frac{d\omega}{dx} + \left(3 + 3\delta_o + \delta_o^2\right)\rho_1 v_1}{\delta_o\left(3 + \delta_o\right)}$$

$$H_0 = \frac{\delta_o\left(3 + 2\delta_o\right)\rho_1 H_1 \frac{\partial u_1}{\partial \omega}\frac{d\omega}{dx} + \left(3 + 3\delta_o + \delta_o^2\right)\rho_1 v_1 H_1 + 3\delta_o R_F}{\delta_o\left(3 + 2\delta_o\right)\rho_1 \frac{\partial u_1}{\partial \omega}\frac{d\omega}{dx} + \left(3 + 3\delta_o + \delta_o^2\right)\rho_1 v_1}$$

These equations contain δ_o, the shock displacement distance at the axis of symmetry ($x = 0$). Since δ_o is initially assumed, a correct value has to be established for the flow-field solution. The regularity conditions at the sonic point, that is, a sonic velocity u_0 and a zero mass flux derivative $\left(\frac{dI_{2,0}}{dx} = 0\right)$, provide the convergence criteria for the proper δ_o.

A Newton-Raphson iteration technique (ref. 2) is used to obtain the set of properties on the body which are consistent with the integrated fluxes. Rankine-Hugoniot relations and the shock angle are used to compute the properties immediately behind the shock. The fluxes ρu, ρuv, and ρuH and the resultant velocity are assumed to vary linearly across the shock layer. Thus, the post-shock and the body properties along with this assumption of linear variation within the shock layer are sufficient to generate consistent velocity components and enthalpies across the entire shock layer. These quantities are computed by the following relations:

$$v_\eta = \frac{I_{4,\eta}}{I_{2,\eta}}$$

$$H_\eta = \frac{I_{5,\eta}}{I_{2,\eta}}$$

$$V_{R,\eta} = V_{R,0} + \left(V_{R,1} - V_{R,0}\right)\eta$$

The pressure distribution is then calculated from the quadratic expression

$$p_\eta = p_0 + \left(\delta Q \rho_0 u_0^2\right)\eta + \left(p_1 - p_0 - \delta Q \rho_0 u_0^2\right)\eta^2$$

The remaining state properties are computed from the equilibrium-air correlations of reference 1.

The integration continues until the pressure at the body diverges, either increasing or decreasing rapidly. This indicates that the sonic point on the body, which is a singular point, has been reached. An increasing divergence of the pressure indicates that the initial δ_0 was too large, and a decreasing divergence of the pressure indicates that δ_0 was too small. The program is stopped after a specified number of iterations on δ_0 or when a maximum value of x which is an input, has been reached.

PROGRAM ORGANIZATION

D1251 Labeled COMMON

The following list contains all the FORTRAN variables appearing in labeled COMMON in the order and with the dimensional information used in program D1251:

COMMON label	FORTRAN variable	Description
/INPUTC/	R	Universal gas constant
	PIN	p_∞
	RHOIN	ρ_∞
	UIN	U_∞
	EMUREF	$\overline{W}_{REF}$
	GAMMA	Ratio of specific heats γ
	RB	Body radius of curvature at axis of symmetry (x = 0)
	RBX	Body radius of curvature at any x-coordinate
	SMALLB	Semimajor axis of an ellipse, nondimensionalized with RB

COMMON label	FORTRAN variable	Description
/INPUTC/	AOVERB	Ratio of semiminor axis to semimajor axis of an ellipse
	XMAX	Maximum value of x allowed
	CII	Initial interval away from singular point of the stagnation streamline
	DELU	Upper limit for δ
	DELL	Lower limit for δ
	R1	Initial guess for weighted heat flux (set equal to zero in this program)
	Z	Used in η distributions ETA = 1./Z Number of points across shock layer where properties are desired
	EPS21	Accuracy criterion for iteration on ρ
	NT	Number of values in EELT array used by INT1
	CCI	Initial computing interval used by INT1
	SSPEC	Print control used by INT1 (if SSPEC = 0, control will be returned after every acceptable integration step; if SSPEC $\neq$ 0, control will be returned at the specified increment of the independent variable)
	CIMAX	Absolute value of maximum computing interval used by INT1
	EELE1(7)	Relative error used by INT1
	ITEXT	Time history print option used by INT1

COMMON label	FORTRAN variable	Description
/INPUTC/	ITTEST	Iteration limit in PROPIT
	TEAN	Initial guess for T'
	RHON	Initial guess for ρ
	TCG	Accuracy criterion on iteration for ρ_0 in RANH
	KKKK	Indicator set in THEP when solution fails near singular point (i.e., when $\rho < 0.00003$)
	KETEST	Number of iterations desired on δ_0
	PIG	Accuracy criterion for the iteration for δ_0 used in CONT
	IGEO	Control in GEO for body shape: 1 sphere 2 ellipsoid 3 hyperboloid
	EELE2(7)	Relative zeros, used by INT1
	EELT(3)	Values for return to program from INT1
/EQVAR/	NE	Number of differential equations to be solved, used by INT1
	IERR	Integer value supplied by INT1 as an error code
	VVAR(8)	Double-precision array used by INT1 which contains the independent variable followed by the dependent variables

COMMON label	FORTRAN variable	Description
/EQVAR/	CCUVAR(8)	Double-precision array used by INT1 to store the values of the independent and dependent variables at which the derivatives will be evaluated in DERSUB
	DDER(8)	Array in which the derivatives are stored
	ERRVAL(8)	Array used by INT1
	COSTB	$\cos \theta_b$
	SINTB	$\sin \theta_b$
	SWMTB	$\sin(\omega - \theta_b)$
	CWMTB	$\cos(\omega - \theta_b)$
	SINSQW	$\sin^2\omega$
	THETAB	θ_b
	SMALRB	r_b
	ZB	axial coordinate
	DELS	δ^2
	W	ω
	UINS	$U_\infty{}^2$
	TIN	T_∞
	US	u_s
	VS	v_s

COMMON label	FORTRAN variable	Description
/EQVAR/	U1	u_1
	V1	v_1
	P1	p_1
	RHO1	ρ_1
	T1	T_1
	CAPH1	H_1
	STAEN1	Static enthalpy at shock
	AO	a_0
	UO	u_0
	VO	v_0
	PO	p_0
	RHOO	ρ_0
	TO	T_0
	CAPHO	H_0
	X	Coordinate along body surface
	STAENO	Static enthalpy at body
	STAENT	Static enthalpy
	Z1	z_1
	ZO	z_0

COMMON label	FORTRAN variable	Description
/EQVAR/	PSTAG	Stagnation pressure
	DAF	$\frac{\delta \cos \theta_b}{r_b}$ computed in DERSUB, used in COEF
	OPERA	$\frac{\sin \theta_b}{r_b}$ computed in DERSUB, used in COEF
	DOSRB	$\frac{\delta}{r_b}$ computed in DERSUB, used in COEF
	QD	$Q\delta$
	CAPQ	Q
	EO1	Coefficient appearing in the differential equations, computed in COEF
	ICOSW	Control to set COSW to exactly 0 when $\omega = \frac{\pi}{2}$
	KEKONT	Counter for the number of iterations for δ_o
	DTBDW	$\frac{d\theta_b}{d\omega}$
	DUSDW	$\frac{du_s}{d\omega}$
	DUIDW	$\frac{du_1}{d\omega}$
	DVIDW	$\frac{dv_1}{d\omega}$
	DPIDW	$\frac{dp_1}{d\omega}$
	DROIDW	$\frac{d\rho_1}{d\omega}$
	DRBDX	$\frac{dr_b}{dx}$
	DTBDX	$\frac{d\theta_b}{dx}$
	DDELDX	$\frac{d\delta}{dx}$

COMMON label	FORTRAN variable	Description	
/EQVAR/	DWDX	$\frac{d\omega}{dx}$	
	HONE	H_1	
	XIO(6)	$I_{j,0}$	(j = 2,3,4,5)
	XI1(6)	$I_{j,1}$	
	DI1DX(6)	$\frac{dI_{j,1}}{dx}$	
	DIODX(6)	$\frac{dI_{j,0}}{dx}$	
	ETA	η	
	DI1DW(6)	$\frac{\partial I_{j,1}}{\partial \omega}$	
	AA1(6)	Coefficients used in the governing differential equations computed in COEF	
	BB1(6)		
	GG1(6)		
	EE1(6)		
	GGO(6)		
	CC1		
	DD1		
	SINW	$\sin \omega$	
	COSW	$\cos \omega$	
/RED/	IREAD	If IREAD = 0, write the input; if IREAD ≠ 0, do not write the input	
/DDD/	DELTN	δ_o	

The following table is a cross-reference between labeled COMMON and D1251 subprograms (where X denotes labeled COMMON appearing in each subprogram):

Subprogram	COMMON label			
	/RED/	/INPUT/	/EQVAR/	/DDD/
EQUILIB	X			
MAIN	X	X	X	X
RANH		X	X	
PROPIT				
CHER		X	X	X
THER				
THEP				
FIRST		X	X	
COEF		X	X	
CALD		X	X	
DERSUB		X	X	
CHSUB				
CONT		X	X	X
GEO		X	X	

D1251 Subprogram Descriptions, Flow Charts, and Listings

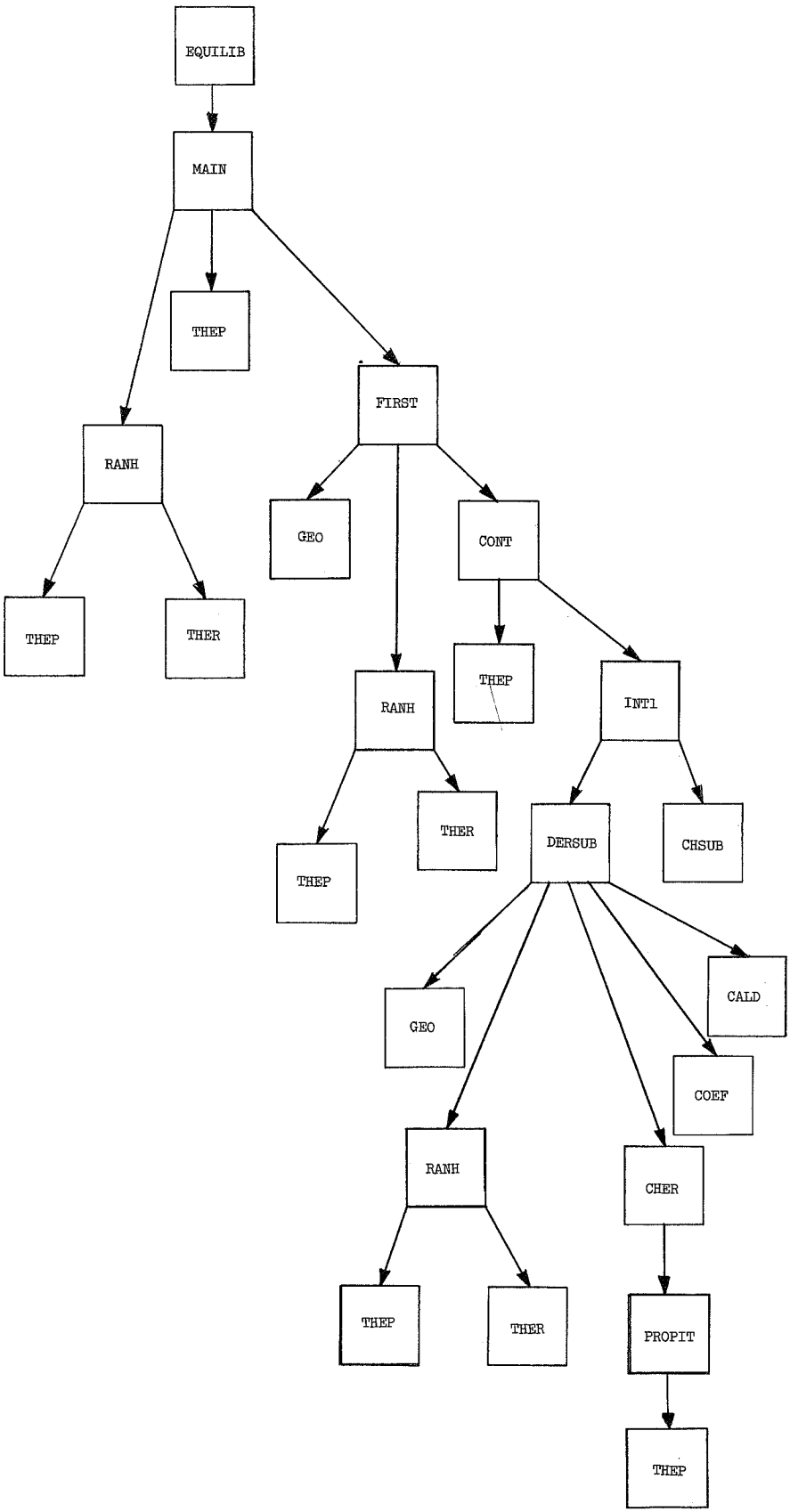
Program D1251 is one of a series of programs developed to analyze blunt-body flow-field data by the method of integral relations. Since many of the same computational procedures were used in the various flow-field programs, each procedure was written as an independent subprogram to be called as needed.

This section of the report presents a brief description of the subprograms used, a statement of the function of each subprogram, individual flow charts, and subprogram listings. A list of each subprogram and its description is given below:

Subprogram	Description
EQUILIB	Writes program title and calls MAIN
MAIN	Reads and writes NAMELIST input, initializes program variables, and computes stagnation-line solution
RANH	Calculates post-shock conditions by use of the Rankine-Hugoniot equations

Subprogram	Description
GEO	Computes the body geometry
FIRST	Computes properties at the first step off stagnation line
THEP	Thermodynamics routine which solves the correlation equation for equilibrium air
THER	Calculates partial derivatives of equilibrium-air properties
CONT	Calls integration routine, computes thermodynamic properties within the shock layer, performs iteration on δ_0 for sphere-pressure results, and writes output
CHER	Performs an additional test on the δ_0 iteration
PROPIT	Iteration subroutine for body properties
COEF	Calculates the coefficients of the governing differential equations
CALD	Computes the governing differential equations which are used in DERSUB
DERSUB	Called by the Runge-Kutta integration routine INT1 to evaluate the derivatives
CHSUB	Called by INT1 to allow the user certain logical control

A directed graph of the FORTRAN subprograms used in program D1251 is given in the flow chart on the following page.


EQUILIB
MAIN
THEP
FIRST
RANH
GEO
CONT
THEP
THER
THEP
RANH
INT1
THER
DERSUB
CHSUB
THEP
GEO
CALD
COEF
RANH
CHER
THEP
THER
PROPIT
THEP

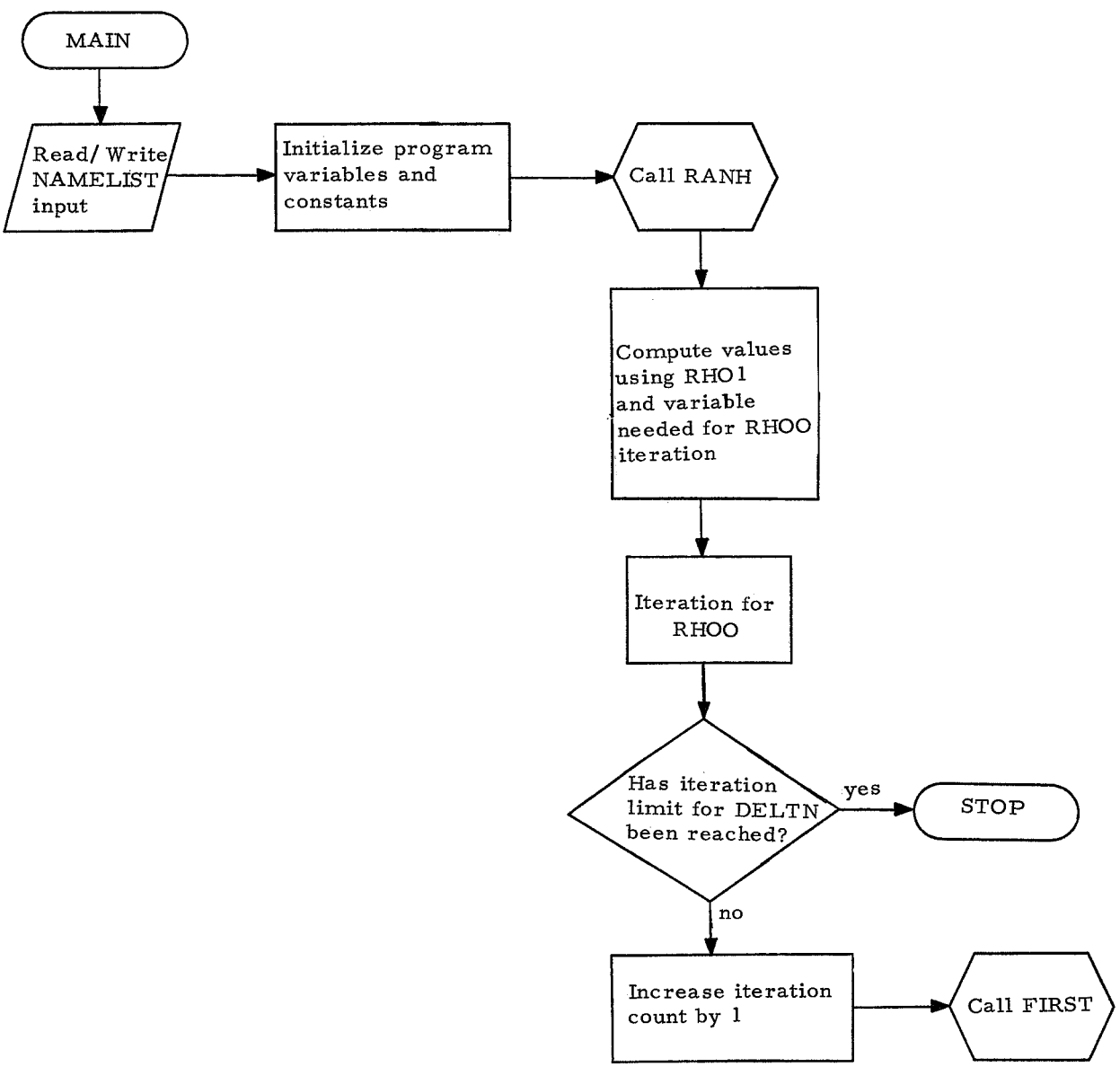
EQUILIB

EQUILIB writes the program identification and calls MAIN.

```
      PROGRAM EQUILIB(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)                A    1
C                                                                           A    2
C                                                                           A    3
C     EQUILIBRIUM AIR   PROGRAMED BY FRANCES W. TAYLOR                      A    4
C                                                                           A    5
C                                                                           A    6
      COMMON /RED/ IREAD                                                    A    7
      IREAD=0                                                               A    8
      WRITE (6,1)                                                           A    9
      CALL MAIN                                                             A   10
      STOP                                                                  A   11
C                                                                           A   12
C                                                                           A   13
1     FORMAT (1H1,20X,48HEQUILIBRIUM AIR   PROGRAMED BY FRANCES W. TAYLOR/  A   14
     1)                                                                     A   15
      END                                                                   A   16-
```

MAIN

The function of subprogram MAIN is to call the NAMELIST input, to initialize the program, and to compute the stagnation-line solution. The stagnation-line solution is obtained by an iteration on ρ_0 with the use of a Newton-Raphson technique. The program is ended after a specific number of iterations on δ_0, which is controlled by the input KETEST, or when a maximum value of x has been reached. The flow chart for subprogram MAIN is given below:



```
      SUBROUTINE MAIN                                                    B    1
      DOUBLE PRECISION VVAR,CCUVAR                                       B    2
C                                                                        B    3
C     INPUT                                                              B    4
C                                                                        B    5
      COMMON /INPUTC/ R,PIN,RHOIN,UIN,EMUREF,GAMMA,RB,RBX,SMALLB,AOVERB, B    6
     1XMAX,CII,DELU,DELL,R1,Z,EPS21,NT,CCI,SSPEC,CIMAX,EELE1(7),ITEXT,IT B    7
     2TEST,TEAN,RHON,TCG,KKKK,KETEST,PIG,IGEO,EELE2(7),EELT(3)           B    8
      COMMON /EQVAR/ NE,IERR,VVAR(8),CCUVAR(8),DDER(8),ERRVAL(8),COSTB,S B    9
     1INTB,SWMTB,CWMTB,SINSQW,THETAB,SMALRB,ZB,DELS,DELTA,W,UINS,TIN,US, B   10
     2VS,U1,V1,P1,RHO1,T1,CAPH1,STAEN1,AO,UO,VO,PO,RHOO,TO,CAPHO,X,STAEN B   11
     30,STAENT,Z1,ZO,PSTAG,DAF,OPERA,DOSRB,QD,CAPQ,EO1,ICONT,ICOSW,KEKON B   12
     4T,DTBDW,DUSDW,DVSDW,DU1DW,DV1DW,DP1DW,DRO1DW,DRBDX,DTBDX,DDELDX,DW B   13
     5DX,HONE,XIO(6),XI1(6),DI1DX(6),DIODX(6),ETA,DI1DW(6),AA1(6),BB1(6) B   14
     6,GG1(6),GGO(6),CC1,DD1,SINW,COSW,KONF,PIO2,EE1(6)                  B   15
      COMMON /RED/ IREAD                                                 B   16
      COMMON /DDD/ DELTN                                                 B   17
C                                                                        B   18
      NAMELIST /IECHEM/ R,PIN,RHOIN,UIN,EMUREF,GAMMA,RB,RBX,SMALLB,AOVER B   19
     1B,XMAX,CII,DELU,DELL,R1,Z,EPS21,NT,CCI,SSPEC,CIMAX,EELE1,EELE2,EEL B   20
     2T,ITEXT,ITTEST,TEAN,RHON,TCG,KETEST,PIG,IGEO                       B   21
C                                                                        B   22
C     INPUT                                                              B   23
C     R         GAS CONSTANT                                             B   24
C     PIN       FREE STREAM PRESSURE                                     B   25
C     RHOIN     FREE STREAM DENSITY                                      B   26
C     UIN       FREE STREAM VELOCITY                                     B   27
C     EMUREF    MOLECULAR WEIGHT OF COLD AIR   USED IN THEP              B   28
C     GAMMA     RATIO OF SPECIFIC HEATS                                  B   29
C     RB        BODY RADIUS AT X=0                                       B   30
C     RBX       BODY RADIUS AT ANY X                                     B   31
C     SMALLB    SEMI MAJOR AXIS OF AN ELLIPSE                            B   32
C     AOVERB    RATIO OF SEMI MINOR AXIS TO SEMI MAJOR AXIS OF ELLIPSE   B   33
C     XMAX      WHEN X=XMAX THE PROGRAM IS STOPPED                       B   34
C     CII       INITIAL LINEAR INTEGRATION STEP IN FIRST                 B   35
C     DELU      UPPER LIMIT FOR DELTA                                    B   36
C     DELL      LOWER LIMIT FOR DELTA                                    B   37
C     R1        INITIAL GUESS FOR WEIGHTED RADIATION HEAT FLUX R1=0 IN   B   38
C               THIS PROGRAM                                             B   39
C     Z         USED FOR ETA DISTRIBUTIONS  ETA=1/Z                      B   40
C     EPS21     ACCURACY CRITERIA FOR RHO ITERATION                      B   41
C     NT        NUMBER OF VALUES    IN ELT ARRAY          USED BY INT1   B   42
C     CCI       INITIAL COMPUTING INTERVAL                USED BY INT1   B   43
C     SSPEC     PRINT CONTROL                             USED BY INT1   B   44
```

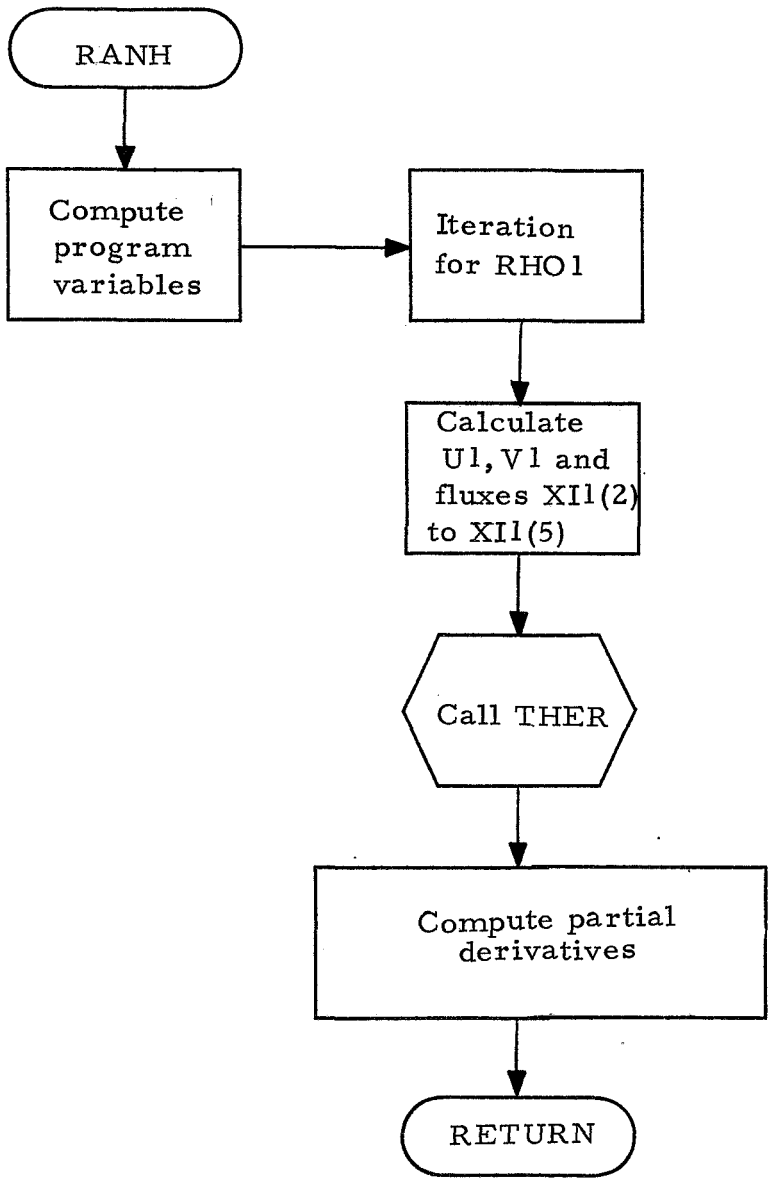
```
C       CIMAX     ABSOLUTE VALUE OF MAXIMUM COMPUTING INTERVAL USED BY INT1   B  45
C       EELE1     RELATIVE ERROR                               USED BY INT1   B  46
C       EELE2     RELATIVE ZERO                                USED BY INT1   B  47
C       ITEXT     TIME HISTORY PRINT OPTION =0 NO PRINTOUT     USED BY INT1   B  48
C       ELT       VALUE FOR RETURN TO PROGRAMS                 USED BY INT1   B  49
C       ITTEST    ITERATION LIMIT IN PROPIT                                   B  50
C       TEAN      INITIAL GUESS FOR STAGNATION TEMPERATURE                    B  51
C       RHON      INITIAL GUESS FOR STAGNATION DENSITY                        B  52
C       TCG       ACCURACY ON ITTERATION FOR DENSITY IN RANH                  B  53
C       KETEST    THE NUMBER OF ITERATIONS DESIRED ON DELTN                   B  54
C       PIG       ACCURACY CRITERIA FOR DELTO IN CONT                         B  55
C       IGEO      A TEST IN GEO ROUTINE FOR SPHERE,ELLIPSOID OR HYPERBOLOID   B  56
C                                                                             B  57
C                                                                             B  58
        IDUM=1                                                                B  59
        IREAD=IREAD+1                                                         B  60
        IF (IREAD-1) 1,1,2                                                    B  61
1       READ (5,IECHEM)                                                       B  62
        IF(EOF,5)7,17
17      WRITE (6,IECHEM)                                                      B  63
        IREAD=IREAD+1                                                         B  64
        KEKONT=0                                                              B  65
        PI02=3.1415927/2.                                                     B  66
2       CIN=CI                                                                B  67
        JTT=0                                                                 B  68
        DELTN=(DELL+DELU)/2.                                                  B  69
        DELTA=DELTN                                                           B  70
        W=PI02                                                                B  71
        THETAB=PI02                                                           B  72
        ICOSW=0                                                               B  73
C                                                                             B  74
C       INITIALIZATION                                                        B  75
C                                                                             B  76
C       PRODUCTS                                                              B  77
C                                                                             B  78
        UINS=UIN**2                                                           B  79
        PALRHM=1.                                                             B  80
        X=0                                                                   B  81
        SMALRB=0                                                              B  82
        DRBDX=1.                                                              B  83
        DTBDX=-1.                                                             B  84
        CAPQ=1.                                                               B  85
        QD=CAPQ*DELTA                                                         B  86
        T=TEAN                                                                B  87
```

```
      CALL RANH                                                          B  88
      TWODEL=2.*DELTA                                                    B  89
      THRDEL=3.*DELTA                                                    B  90
      DELS=DELTA**2                                                      B  91
      AC=TWODEL*(3.+TWODEL)*RHO1*V1*DU1DW                                B  92
      BC=-2.*(3.+THRDEL+DELS)                                            B  93
      CC=2.*(3.+THRDEL+DELS)*P1+2.*(3.+THRDEL+DELS)*RHO1*V1**2           B  94
      DC=TWODEL*(3.+DELTA)                                               B  95
      EC=-BC*RHO1*V1                                                     B  96
      FC=6.*DELTA                                                        B  97
      GC=2.*(3.+THRDEL+DELS)*RHO1*V1*HONE                                B  98
      UO=0                                                               B  99
      PO=P1+.5*RHO1*V1**2                                                B 100
      VO=0                                                               B 101
      COSRB=1.                                                           B 102
      SINTB=1.                                                           B 103
      GGO(4)=PO                                                          B 104
      GG1(4)=P1+RHO1*V1**2                                               B 105
      XI1(3)=P1+RHO1*U1**2                                               B 106
      XIO(3)=PO                                                          B 107
      DIM=2.*DELTA*SINTB/DRBDX                                           B 108
      DWDX=-(BC*PO+CC)/AC                                                B 109
      WRITE (6,8) DWDX                                                   B 110
      RHOOAO=-(AC/V1*DWDX+EC)/DC                                         B 111
      CAPHO=-(AC*HONE/V1*DWDX+FC*R1+GC)/(DC*RHOOAO)                      B 112
      RHODUM=RHON                                                        B 113
      STAENT=CAPHO                                                       B 114
3     CALL THEP (R,PDUM,RHODUM,TO,ZO,STAENT,EMUREF,PIN,RHOIN,UINS,KKKK)  B 115
      GRODUM=PDUM                                                        B 116
      FRODUM=PDUM-PO                                                     B 117
      DELRHO=.1                                                          B 118
      RHODMP=RHODUM+DELRHO                                               B 119
      CALL THEP (R,PDUM,RHODMP,TX,ZX,STAENT,EMUREF,PIN,RHOIN,UINS,KKKK)  B 120
      FPRHO=(PDUM-GRODUM)/DELRHO                                         B 121
      FROFPR=FRODUM/FPRHO                                                B 122
      AFRFPR=ABS(FROFPR)                                                 B 123
      IF (AFRFPR-EPS21) 5,5,4                                            B 124
4     RHODUM=RHODUM-FROFPR                                               B 125
      GO TO 3                                                            B 126
5     RHOO=RHODUM                                                        B 127
      AO=RHOOAO/RHOO                                                     B 128
C                                                                        B 129
C     KEKONT COUNTS THE NUMBER OF PASSES THRU MAIN. KETEST IS THE LIMIT  B 130
C     ON THE NUMBER OF PASSES.                                           B 131
```

```
C                                                                      B 132
C     TEST KEKONT                                                      B 133
C                                                                      B 134
      IF (KEKONT-KETEST) 6,7,7                                         B 135
6     KEKONT=KEKONT+1                                                  B 136
      DELTA=(DELL+DELU)/2.                                             B 137
      PSTAG=PO                                                         B 138
      CALL FIRST                                                       B 139
7     STOP                                                             B 140
C                                                                      B 141
C                                                                      B 142
8     FORMAT (1H16X4HDWDXE15.8/)                                       B 143
      END                                                              B 144-
```

RANH

RANH computes the post-shock conditions (properties, fluxes, and partial derivatives with respect to ω) with the use of the Rankine-Hugoniot equations. It is called by MAIN for the stagnation-line solution and then by DERSUB in each integration step. The flow chart for subprogram RANH is given below:

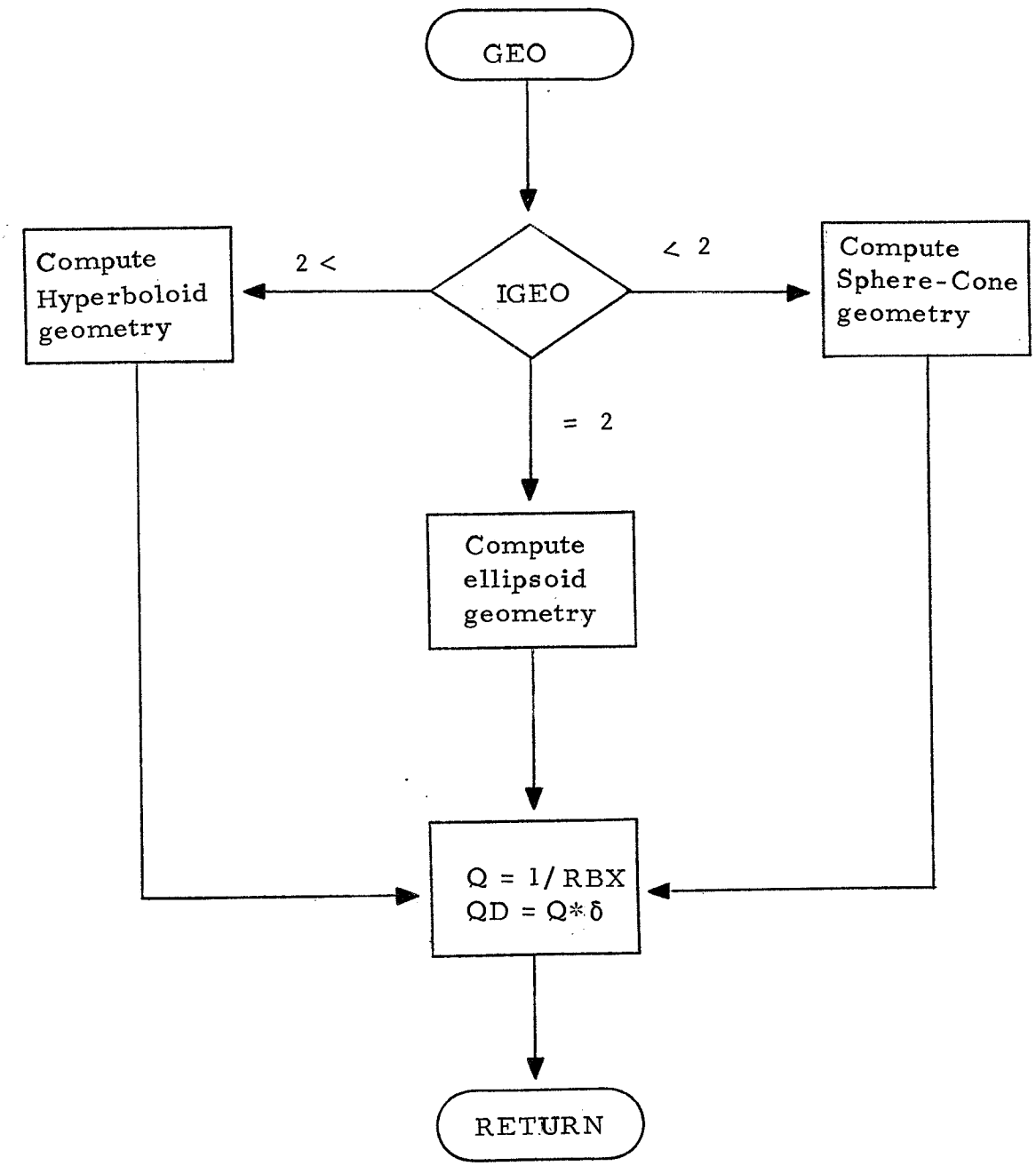


```
      SUBROUTINE RANH                                                    M    1
      DOUBLE PRECISION VVAR,CCUVAR                                       M    2
C                                                                        M    3
C     INPUT                                                              M    4
C                                                                        M    5
      COMMON /INPUTC/ R,PIN,RHOIN,UIN,EMUREF,GAMMA,RB,RBX,SMALLB,AOVERB, M    6
     1XMAX,CII,DELU,DELL,R1,Z,EPS21,NT,CCI,SSPEC,CIMAX,EELE1(7),ITEXT,IT M    7
     2TEST,TEAN,RHON,TCG,KKKK,KETEST,PIG,IGEO,EELE2(7),EELT(3)           M    8
      COMMON /EQVAR/ NE,IERR,VVAR(8),CCUVAR(8),DDER(8),ERRVAL(8),COSTB,S M    9
     1INTB,SWMTB,CWMTB,SINSQW,THETAB,SMALRB,ZB,DELS,DELTA,W,UINS,TIN,US, M   10
     2VS,U1,V1,P1,RHO1,T1,CAPH1,STAEN1,AO,UO,VO,PO,RHOO,TO,CAPHO,X,STAEN M   11
     30,STAENT,Z1,ZO,PSTAG,DAF,OPERA,DOSRB,QD,CAPQ,EO1,ICONT,ICOSW,KEKON M   12
     4T,DTBDW,DUSDW,DVSDW,DU1DW,DV1DW,DP1DW,DRO1DW,DRBDX,DTBDX,DDELDX,DW M   13
     5DX,HONE,XIO(6),XI1(6),DI1DX(6),DIODX(6),ETA,DI1DW(6),AA1(6),BB1(6) M   14
     6,GG1(6),GGO(6),CC1,DD1,SINW,COSW,KONF,PIO2,EE1(6)                  M   15
C                                                                        M   16
C                                                                        M   17
C     RANKINE HUGONIOT RELATIONS FOR EQUILIBRIUM COMPOSITION             M   18
C                                                                        M   19
      DTBDW=0                                                            M   20
      SINW=SIN(W)                                                        M   21
      IF (ICOSW) 1,1,2                                                   M   22
1     COSW=0                                                             M   23
      SWMTB=0                                                            M   24
      GO TO 3                                                            M   25
2     COSW=COS(W)                                                        M   26
      SWMTB=SIN(W-THETAB)                                                M   27
3     CWMTB=COS(W-THETAB)                                                M   28
      SWS=SINW**2                                                        M   29
      US=COSW                                                            M   30
      RHO1=RHON                                                          M   31
4     VS=-SINW/RHO1                                                      M   32
      CAPH1=.5+3.5*PIN/(RHOIN*UINS)                                      M   33
      HONE=CAPH1                                                         M   34
      STAENT=CAPH1-(US**2+VS**2)/2.                                      M   35
      STAEN1=STAENT                                                      M   36
      CALL THEP (R,P1,RHO1,T1,Z1,STAENT,EMUREF,PIN,RHOIN,UINS,KKKK)      M   37
      RHO1P=(PIN/(RHOIN*UINS)+SWS-P1)/VS**2                              M   38
      FRHO1=RHO1-RHO1P                                                   M   39
      DELRO1=.1                                                          M   40
      RHO1D=RHO1+DELRO1                                                  M   41
      VP=-SINW/RHO1D                                                     M   42
      STAP=CAPH1-(US**2+VP**2)/2.                                        M   43
      CALL THEP (R,PD,RHO1D,TX,ZX,STAP,EMUREF,PIN,RHOIN,UINS,KKKK)       M   44
```

```
      RHO1DP=(PIN/(RHOIN*UINS)+SWS-PD)/VP**2                                  M  45
      FPRHO1=(RHO1D-RHO1DP-FRHO1)/DELRO1                                      M  46
      AFMFP=ABS(FRHO1/FPRHO1)                                                 M  47
      IF (AFMFP-TCG) 6,6,5                                                    M  48
5     RHO1=RHO1-FRHO1/FPRHO1                                                  M  49
      GO TO 4                                                                 M  50
6     U1=US*CWMTB-VS*SWMTB                                                    M  51
      V1=US*SWMTB+VS*CWMTB                                                    M  52
      XI1(2)=RHO1*U1                                                          M  53
      XI1(3)=P1+RHO1*U1**2                                                    M  54
      XI1(4)=RHO1*U1*V1                                                       M  55
      XI1(5)=RHO1*U1*CAPH1                                                    M  56
      XI1(1)=0                                                                M  57
      CALL THER (R,P1,RHO1,STAENT,EMUREF,PIN,RHOIN,UINS,C1P,C2P,C1D,C2D)      M  58
      DRO1DW=SINW*COSW*(C1D*(1.-1./RHO1**2)-2.*(1.-1./RHO1))/((SWS/RHO1*      M  59
     1*2)*(1.-C1D/RHO1)-C2D)                                                  M  60
      DSH1DW=SINW*COSW*(1.-1./RHO1**2)+SWS/RHO1**3*DRO1DW                     M  61
      DP1DW=C1D*DSH1DW+C2D*DRO1DW                                             M  62
      DUSDW=-SINW                                                             M  63
      DVSDW=-1./RHO1*(US+VS/RHO1*DRO1DW)                                      M  64
      DU1DW=DUSDW*CWMTB-DVSDW*SWMTB-US*SWMTB*(1.-DTBDW)-VS*CWMTB*(1.-DTB      M  65
     1DW)                                                                     M  66
      DV1DW=DUSDW*SWMTB+DVSDW*CWMTB+US*CWMTB*(1.-DTBDW)-VS*SWMTB*(1.-DTB      M  67
     1DW)                                                                     M  68
      DCH1DW=0                                                                M  69
      DI1DW(2)=RHO1*DU1DW+U1*DRO1DW                                           M  70
      DI1DW(3)=DP1DW+2.*RHO1*U1*DU1DW+U1**2*DRO1DW                            M  71
      DI1DW(4)=RHO1*V1*DU1DW+RHO1*U1*DV1DW+U1*V1*DRO1DW                       M  72
      DI1DW(5)=CAPH1*DI1DW(2)                                                 M  73
      RETURN                                                                  M  74
      END                                                                     M  75-
```

GEO

Subprogram GEO computes the body geometry. The user has a choice of three body shapes which are controlled by an input IGEO. IGEO = 1 computes sphere geometry, IGEO = 2 computes ellipsoid geometry, and IGEO = 3 computes hyperboloid geometry. GEO is called by MAIN for the stagnation-line solution and by DERSUB for each integration step. The flow chart for subprogram GEO is given below:

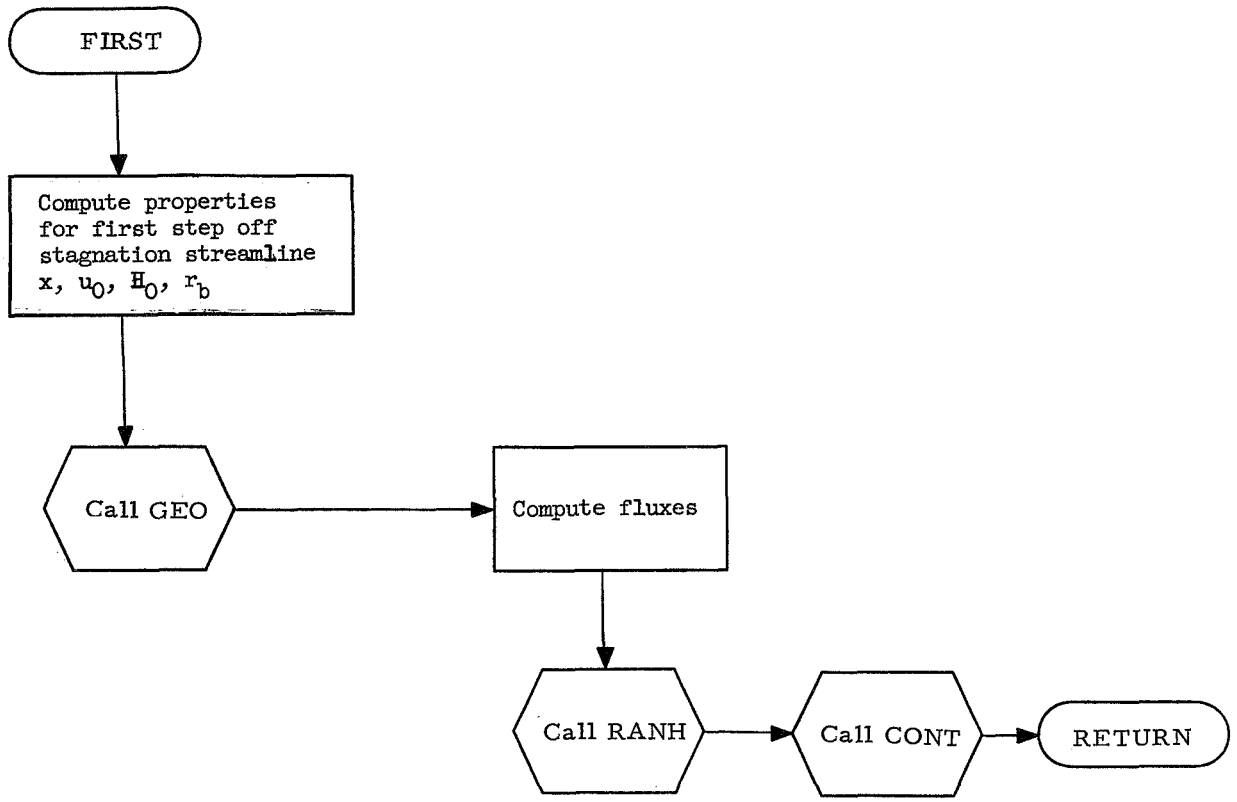


```
      SUBROUTINE GEO                                                    L    1
C                                                                       L    2
C     INPUT                                                             L    3
      DOUBLE PRECISION VVAR,CCUVAR                                      L    4
      COMMON /INPUTC/ R,PIN,RHOIN,UIN,EMUREF,GAMMA,RB,RBX,SMALLB,AOVERB,L    5
     1XMAX,CII,DELU,DELL,R1,Z,EPS21,NT,CCI,SSPEC,CIMAX,EELE1(7),ITEXT,IT L    6
     2TEST,TEAN,RHON,TCG,KKKK,KETEST,PIG,IGEO,EELE2(7),EELT(3)          L    7
      COMMON /EQVAR/ NE,IERR,VVAR(8),CCUVAR(8),DDER(8),ERRVAL(8),COSTB,S L    8
     1INTB,SWMTB,CWMTB,SINSQW,THETAB,SMALRB,ZB,DELS,DELTA,W,UINS,TIN,US, L    9
     2VS,U1,V1,P1,RHO1,T1,CAPH1,STAEN1,AO,UO,VO,PO,RHOO,TO,CAPHO,X,STAEN L   10
     30,STAENT,Z1,ZO,PSTAG,DAF,OPERA,DOSRB,QD,CAPQ,EO1,ICONT,ICOSW,KEKON L   11
     4T,DTBDW,DUSDW,DVSDW,DU1DW,DV1DW,DP1DW,DRO1DW,DRBDX,DTBDX,DDELDX,DW L   12
     5DX,HONE,XIO(6),XI1(6),DI1DX(6),DIODX(6),ETA,DI1DW(6),AA1(6),BB1(6) L   13
     6,GG1(6),GGO(6),CC1,DD1,SINW,COSW,KONF,PIO2,EE1(6)                 L   14
C                                                                       L   15
C     IGEO=1 COMPUTE SPHERE GEOMETRY    IGEO=2 COMPUTE ELLIPSOID GEOMETR L   16
C     IGEO=3 COMPUTE HYPERBOLOID GEOMETRY                               L   17
C                                                                       L   18
      SMALLB=AOVERB                                                     L   19
      IF (IGEO-2) 1,2,3                                                 L   20
C                                                                       L   21
C     SPHERE - CONF                                                     L   22
C                                                                       L   23
C                                                                       L   24
1     SMALRB=SIN(X)                                                     L   25
      THETAB=PIO2-X                                                     L   26
      DRBDX=COS(X)                                                      L   27
      DTBDX=-1.                                                         L   28
      RBX=1.                                                            L   29
      GO TO 4                                                           L   30
C     ELLIPSOID                                                         L   31
2     BSQ=SMALLB**2                                                     L   32
      RSQ=SMALRB**2                                                     L   33
      BSMRS=BSQ-RSQ                                                     L   34
      RACE=RSQ/BSMRS                                                    L   35
      ZB=AOVERB*SMALLB-AOVERB*SQRT(BSMRS)                               L   36
      AAA=AOVERB*SMALLB                                                 L   37
      PTAN=((SMALLB/AAA)*(AAA-ZB))/(SQRT(2.*AAA*ZB-ZB**2))              L   38
      THETAB=ATAN(PTAN)                                                 L   39
      RBX=((1.+AOVERB**2*RACE)**(3./2.))/(AOVERB/SQRT(BSMRS)*(1.+RACE)) L   40
      CAPQ=1./RBX                                                       L   41
      DTBDX=-CAPQ                                                       L   42
      GO TO 4                                                           L   43
C     HYPERBOLOID                                                       L   44
```

```
C                                                                                    L  45
3       BSQ=SMALLB**2                                                                L  46
        RSQ=SMALRB**2                                                                L  47
        BSPRS=BSQ+RSQ                                                                L  48
        RACH=RSQ/BSPRS                                                               L  49
        AAA=AOVERB*SMALLB                                                            L  50
        SQBSPRS=SQRT(BSPRS)                                                          L  51
        ZB=-AAA+AOVERB*SQBSPRS                                                       L  52
        PTAN=SQBSPRS/(AOVERB*SMALRB)                                                 L  53
        THETAB=ATAN(PTAN)                                                            L  54
        RBX=((1.+AOVERB**2*RACH)**(3./2.))/(AOVERB/SQBSPRS*(1.-RACH))                L  55
4       CAPQ=1./RBX                                                                  L  56
        QD=CAPQ*DELTA                                                                L  57
        RETURN                                                                       L  58
        END                                                                          L  59-
```

FIRST

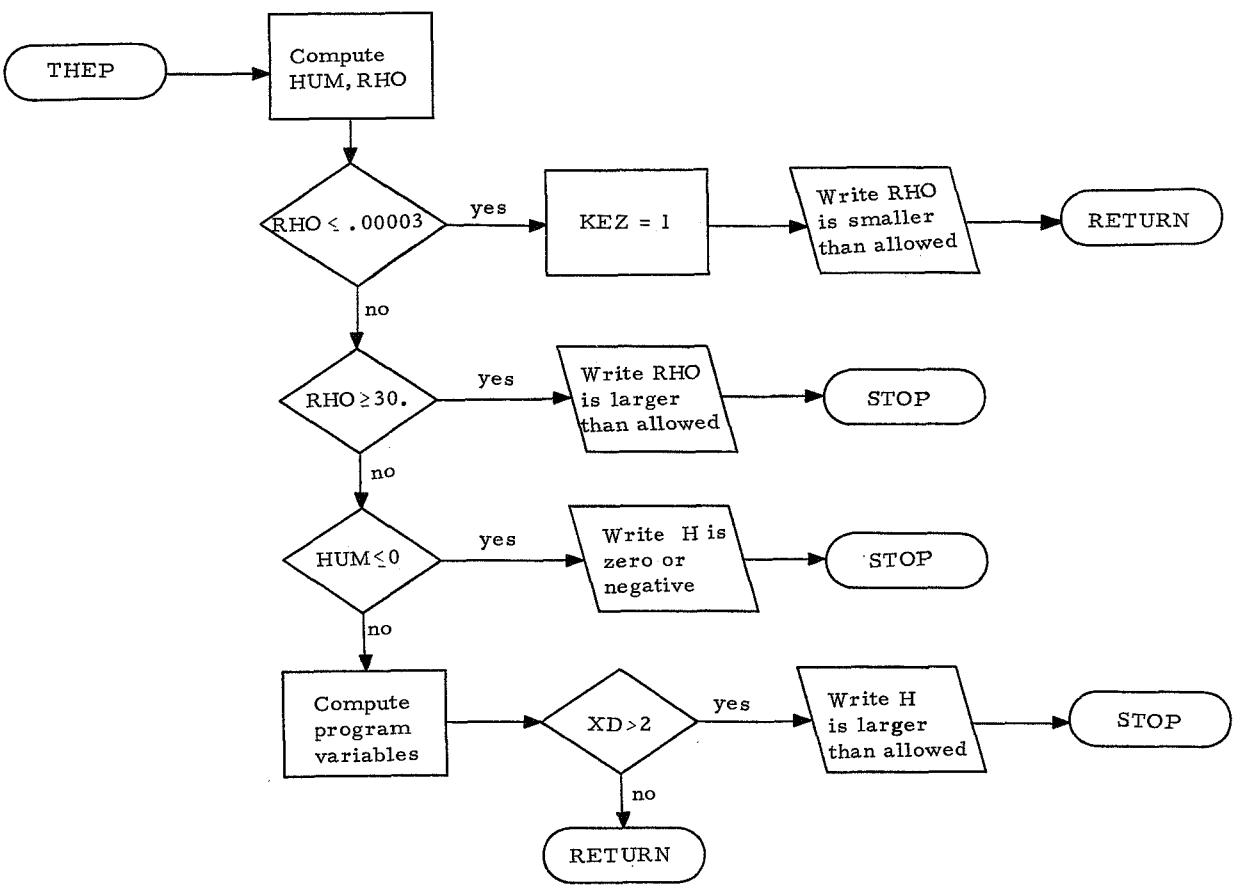
Subprogram FIRST is used to compute the properties at the first step off the stagnation line. The integration cannot start at the stagnation point since it is a singular point. The flow chart for subprogram FIRST is given below:



```
      SUBROUTINE FIRST                                                  I    1
C     INPUT                                                             I    2
      DOUBLE PRECISION VVAR,CCUVAR                                      I    3
      COMMON /INPUTC/ R,PIN,RHOIN,UIN,EMUREF,GAMMA,RB,RBX,SMALLB,AOVERB,I    4
     1XMAX,CII,DELU,DELL,R1,Z,EPS21,NT,CCI,SSPEC,CIMAX,EELE1(7),ITEXT,IT I    5
     2TEST,TEAN,RHON,TCG,KKKK,KETEST,PIG,IGEO,EELE2(7),EELT(3)          I    6
      COMMON /EQVAR/ NE,IERR,VVAR(8),CCUVAR(8),DDER(8),ERRVAL(8),COSTB,S I    7
     1INTB,SWMTB,CWMTB,SINSQW,THETAB,SMALRB,ZB,DELS,DELTA,W,UINS,TIN,US, I    8
     2VS,U1,V1,P1,RHO1,T1,CAPH1,STAEN1,AO,UO,VO,PO,RHOO,TO,CAPHO,X,STAEN I    9
     30,STAENT,Z1,ZO,PSTAG,DAF,OPERA,DOSRB,QD,CAPQ,EO1,ICONT,ICOSW,KEKON I   10
     4T,DTBDW,DUSDW,DVSDW,DU1DW,DV1DW,DP1DW,DRO1DW,DRBDX,DTBDX,DDELDX,DW I   11
     5DX,HONE,XIO(6),XI1(6),DI1DX(6),DIODX(6),ETA,DI1DW(6),AA1(6),BB1(6) I   12
     6,GG1(6),GGO(6),CC1,DD1,SINW,COSW,KONF,PIO2,EE1(6)                 I   13
C                                                                       I   14
      X=CII                                                             I   15
      ICOSW=1                                                           I   16
      UO=AO*CII                                                         I   17
      W=W+DWDX*CII                                                      I   18
      CAPHO=CAPHO+UO**2/2.                                              I   19
      SMALRB=CII                                                        I   20
      CALL GEO                                                          I   21
      THETAB=PIO2+DTBDX*CII                                             I   22
      DELTA=DELTA-((1.+QD)/CAPQ)*(W-THETAB)*DTBDX*CII                   I   23
      XIO(2)=RHOO*UO                                                    I   24
      XIO(3)=PO+RHOO*UO**2                                              I   25
      XIO(4)=RHOO*VO*UO                                                 I   26
      XIO(5)=RHOO*UO*CAPHO                                              I   27
1     CALL RANH                                                         I   28
      CALL CONT                                                         I   29
      RETURN                                                            I   30
      END                                                               I   31-
```

THEP

THEP is the thermodynamics routine that solves the correlation equations for equilibrium air (ref. 1). THEP is called by MAIN, RANH, PROPIT, and CONT. It has a calling sequence in which R, EMUREF, and the free-stream conditions PIN, RHOIN, and UINS are constants. The values of density RHODUM and static enthalpy STAENT are given at the particular point at which THEP is called. The corresponding pressure PDUM, temperature TDUM, and compressibility ZDUM are calculated. There is an indicator KEZ which is set to 1 if "RHO IS SMALLER THAN ALLOWED." This is only used in PROPIT. When KEZ = 1, PROPIT returns immediately to CHER. CHER then sets DELL = DELTN and calls MAIN. The program starts again with a new δ_o. The flow chart for subprogram THEP is given below:

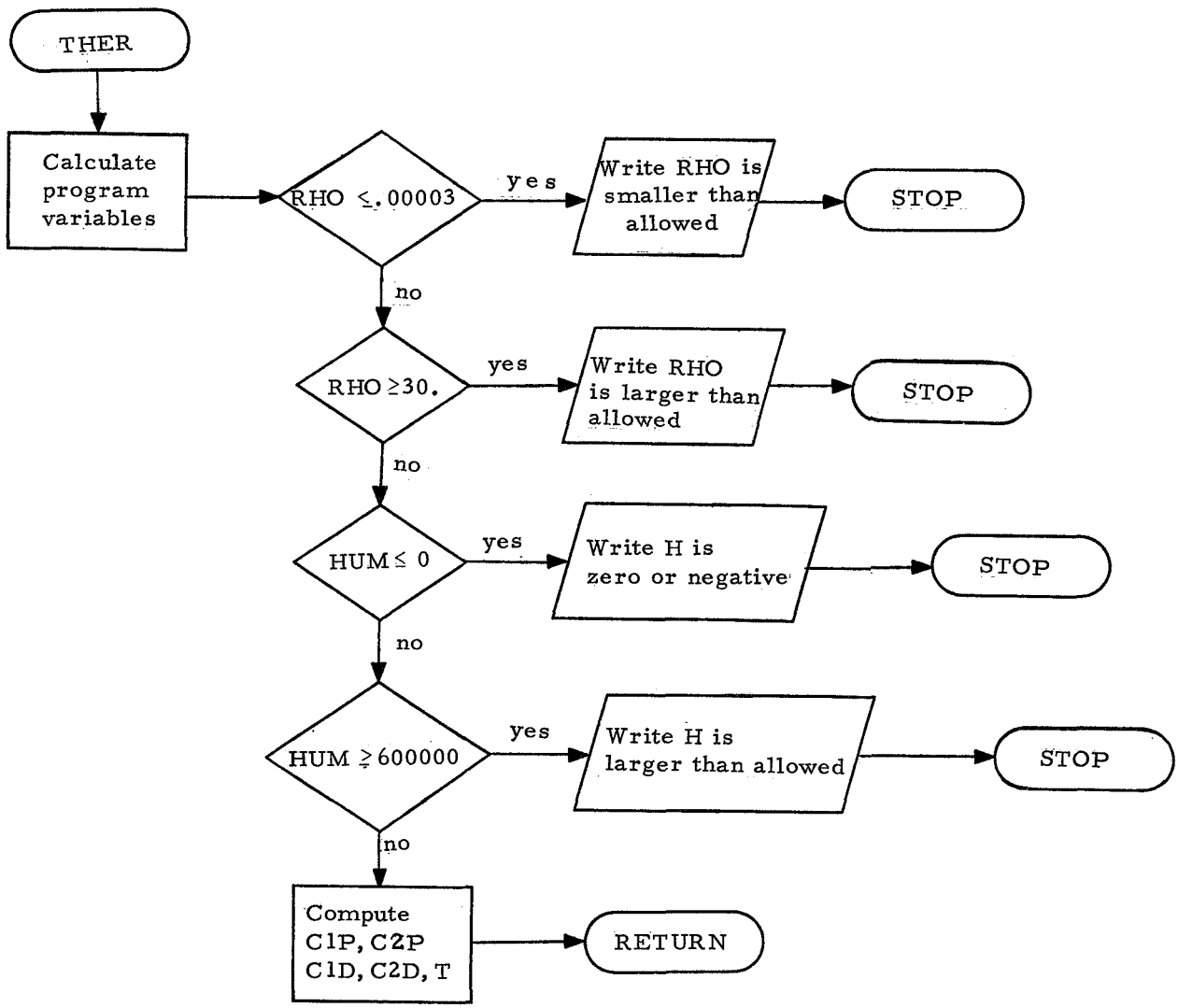


```
      SUBROUTINE THEP (R,PDUM,RHODUM,TDUM,ZDUM,STAENT,EMUREF,PIN,RHOIN,U   G    1
     1INS,KEZ)                                                             G    2
C                                                                          G    3
C                                                                          G    4
C     IF RHO IS SMALLER THAN ALLOWED WHEN THEP IS CALLED FROM PROPIT       G    5
C     THEN KEZ = 1 IN THEP AND   THE PROGRAM RETURNS TO CHER. IN CHER      G    6
C     DELL=DELTN AND MAIN IS CALLED  - THE PROGRAM STARTS WITH A NEW DEL   G    7
C                                                                          G    8
C                                                                          G    9
      KEZ=0                                                                G   10
      HUM=EMUREF*UINS*STAENT/R                                             G   11
      RHO=RHOIN/1.29313E-3*RHODUM                                          G   12
      IF (RHO.LE..00003) GO TO 12                                          G   13
      IF (RHO.GE.30.) GO TO 13                                             G   14
      IF (HUM.LE.0.) GO TO 10                                              G   15
      IF (HUM.GT.5800.) GO TO 1                                            G   16
      P=(.975134E-3)*HUM*RHO                                               G   17
      Z=1.0                                                                G   18
      GO TO 9                                                              G   19
1     IF (HUM.GT.10500.) GO TO 2                                           G   20
      P=.00345*RHO*EXP(.854*ALOG(HUM))                                     G   21
      Z=1.0                                                                G   22
      GO TO 9                                                              G   23
2     IF (HUM.GE.35500.) GO TO 3                                           G   24
      RHOLOG=ALOG10(RHO)                                                   G   25
      XD=5.*ALOG10(HUM)-20.                                                G   26
      PLOG=.955+RHOLOG+(.1545+.0131*RHOLOG)*XD+.016*RHOLOG*XD*(2.75-XD)-   G   27
     1.005*XD*(4.-XD)*(1.+RHOLOG)                                          G   28
      P=EXP(2.302585*PLOG)                                                 G   29
      GO TO 5                                                              G   30
3     DV=1.565+1.036*ALOG10(RHO)                                           G   31
      IF (HUM.GE.178000.) GO TO 4                                          G   32
      XD=5.*ALOG10(HUM)-24.                                                G   33
      PLOG=.1336*XD+.00934*XD**3+DV                                        G   34
      P=EXP(2.302585*PLOG)                                                 G   35
      GO TO 5                                                              G   36
4     IF (HUM.GE.600000.) GO TO 11                                         G   37
      PLOG=.95*ALOG10(HUM)-4.58+DV                                         G   38
      P=EXP(2.302585*PLOG)                                                 G   39
      GO TO 5                                                              G   40
C     COMPUTE Z(H,RHO)                                                     G   41
5     XI=1.0-ALOG10(RHO)                                                   G   42
      XD=ALOG10(HUM)-4.+.052*XI-.004*XI**2                                 G   43
      IF (XD.GT.0.) GO TO 6                                                G   44
```

```
      Z=1.0                                                              G  45
      GO TO 9                                                            G  46
6     IF (XD.GT.0.55) GO TO 7                                            G  47
      Z=1.0+.53*XD**2                                                    G  48
      GO TO 9                                                            G  49
7     IF (XD.GE.1.3) GO TO 8                                             G  50
      XI=1.3-XD                                                          G  51
      Z=2.0+XI*(-1.78+XI*(.21+XI*(1.09-.446*XI*XI)))                     G  52
      GO TO 9                                                            G  53
8     IF (XD.GE.2.) GO TO 11                                             G  54
      XI=1.9-XD                                                          G  55
      Z=3.831+XI*(-5.019+XI*(3.41+.24*XI))                               G  56
9     T=(273.*P)/(Z*RHO)                                                 G  57
      ZDUM=Z                                                             G  58
      TDUM=T                                                             G  59
      PDUM=1.01325E6*P/(RHOIN*UINS)                                      G  60
      GO TO 14                                                           G  61
10    WRITE (6,16)                                                       G  62
      GO TO 15                                                           G  63
11    WRITE (6,17)                                                       G  64
      GO TO 15                                                           G  65
12    WRITE (6,18)                                                       G  66
      KEZ=1                                                              G  67
      GO TO 14                                                           G  68
13    WRITE (6,19)                                                       G  69
      GO TO 15                                                           G  70
14    RETURN                                                             G  71
15    STOP                                                               G  72
C                                                                        G  73
C                                                                        G  74
16    FORMAT (10X22HH IS ZERO OR NEGATIVE )                              G  75
17    FORMAT (10X25HH IS LARGER THAN ALLOWED )                           G  76
18    FORMAT (10X28HRHO IS SMALLER THAN ALLOWED )                        G  77
19    FORMAT (10X27HRHO IS LARGER THAN ALLOWED )                         G  78
      END                                                                G  79-
```

THER

Subprogram THER is called by RANH to calculate the partial derivatives of equilibrium-air properties which are used in computing the derivatives at the shock wave. THER has a calling sequence in which R, EMUREF, and the free-stream conditions PIN, RHOIN, and UINS are constants. PDUM (P1), RHODUM (RHO1), and STAENT are computed in RANH. The quantities C1P ($\partial\rho/\partial h$) and C2P ($\partial\rho/\partial p$) are calculated in THER. The flow chart for subprogram THER is shown below:

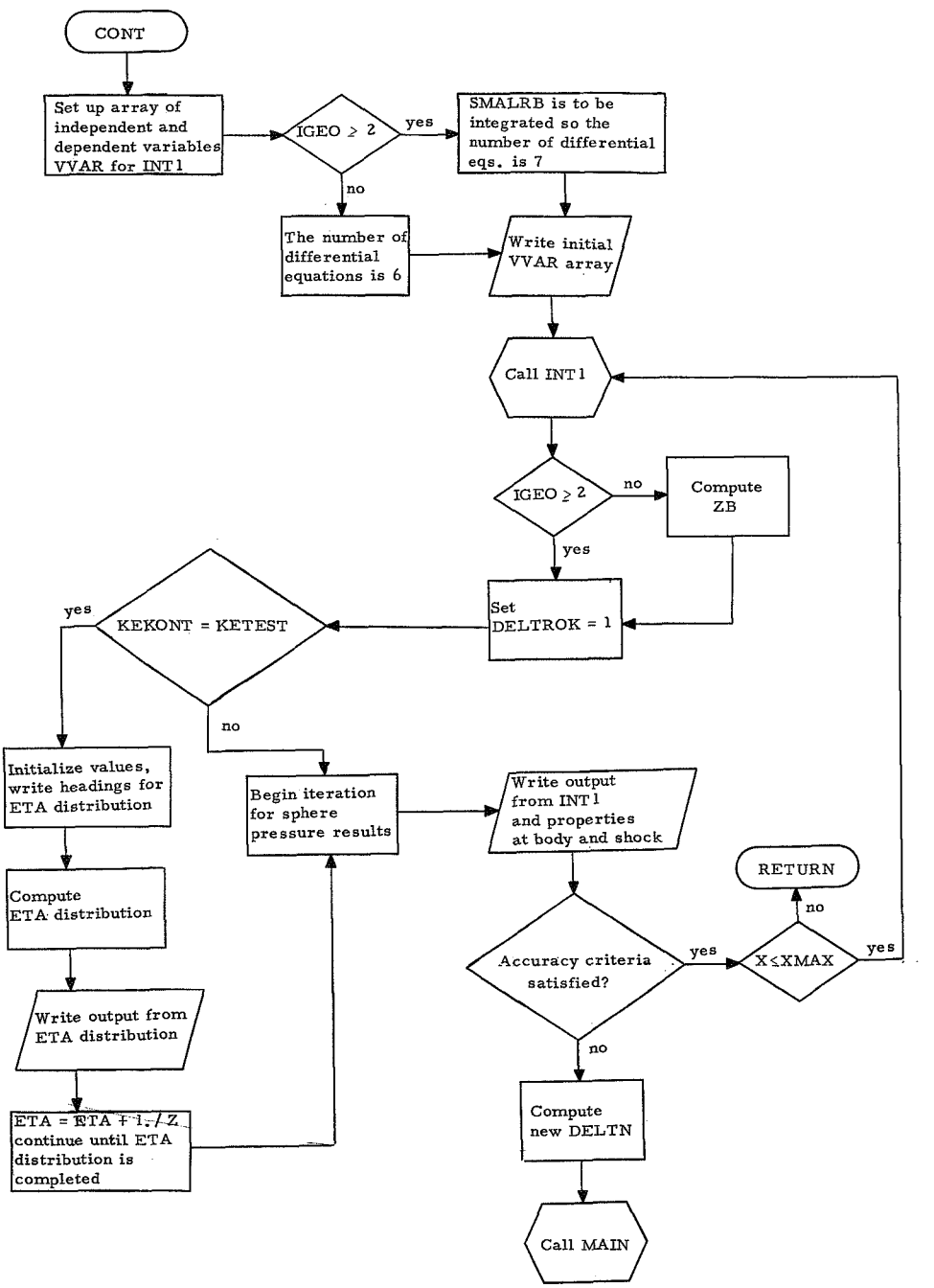


```
      SUBROUTINE THER (R,PDUM,RHODUM,STAENT,EMUREF,PIN,RHOIN,UINS,C1P,C2  F    1
     1P,C1D,C2D)                                                          F    2
C                                                                         F    3
C                                                                         F    4
      Z=ZDUM                                                              F    5
      P=PDUM                                                              F    6
      HUM=EMUREF*UINS*STAENT/R                                            F    7
      RHO=RHOIN/1.29313E-3*RHODUM                                         F    8
      RUN=1.                                                              F    9
      XC1PDP=5.*ALOG10(HUM)-20.                                           F   10
      IF (RHO.LE..00003) GO TO 8                                          F   11
      IF (RHO.GE.30.) GO TO 9                                             F   12
      IF (HUM.LE.0.) GO TO 6                                              F   13
      IF (HUM.GT.5800.) GO TO 1                                           F   14
      C1P=.975134E-3/RUN*RHO                                              F   15
      C2P=.975134E-3*HUM                                                  F   16
      GO TO 5                                                             F   17
1     IF (HUM.GT.10500.) GO TO 2                                          F   18
      C1P=.345E-2*.854*RHO/(RUN*HUM**.146)                                F   19
      C2P=.345E-2*HUM                                                     F   20
      GO TO 5                                                             F   21
2     IF (HUM.GE.35500.) GO TO 3                                          F   22
      C1P=5.*P/(HUM*RUN)*(.1545+(.0131+.016*(2.75-2.*XC1PDP))*ALOG10(RHO   F   23
     1)-.005*(4.-2.*XC1PDP)*(1.+ALOG10(RHO)))                             F   24
      C2P=P/RHO*(1.+XC1PDP*(.0131+.016*(2.75-XC1PDP))-.005*(4.-XC1PDP))    F   25
      GO TO 5                                                             F   26
3     DV=1.565+1.036*ALOG10(RHO)                                          F   27
      IF (HUM.GE.178000.) GO TO 4                                         F   28
      C2P=1.036*P/RHO                                                     F   29
      C1P=5.*P/(HUM*RUN)*(.1336+.02802*(5.*ALOG10(HUM)-24.)**2)           F   30
      GO TO 5                                                             F   31
4     IF (HUM.GE.600000.) GO TO 7                                         F   32
      C1P=.95*P/(HUM*RUN)                                                 F   33
      C2P=1.036*P/RHO                                                     F   34
5     C1D=C1P*1.01325E6/(RHOIN*R)*EMUREF                                  F   35
      C2D=C2P*1.01325E6/(1.29313E-3*UINS)                                 F   36
      GO TO 11                                                            F   37
6     WRITE (6,12)                                                        F   38
      GO TO 10                                                            F   39
7     WRITE (6,13)                                                        F   40
      GO TO 10                                                            F   41
8     WRITE (6,14)                                                        F   42
      GO TO 10                                                            F   43
9     WRITE (6,15)                                                        F   44
```

```
      GO TO 10                                                          F  45
10    STOP                                                              F  46
11    RETURN                                                            F  47
C                                                                       F  48
C                                                                       F  49
12    FORMAT (10X22HH IS ZERO OR NEGATIVE )                             F  50
13    FORMAT (10X25HH IS LARGER THAN ALLOWED )                          F  51
14    FORMAT (10X28HRHO IS SMALLER THAN ALLOWED )                       F  52
15    FORMAT (10X27HRHO IS LARGER THAN ALLOWED )                        F  53
      END                                                               F  54-
```

CONT

In subprogram CONT the array of independent variables is established and INT1, the integration routine, is called. The thermodynamic properties within the shock layer are computed in the η distribution. An iteration is performed on δ_o for sphere-pressure results. The output from the integration and the η distribution are written in CONT. The flow chart for subprogram CONT is given below:



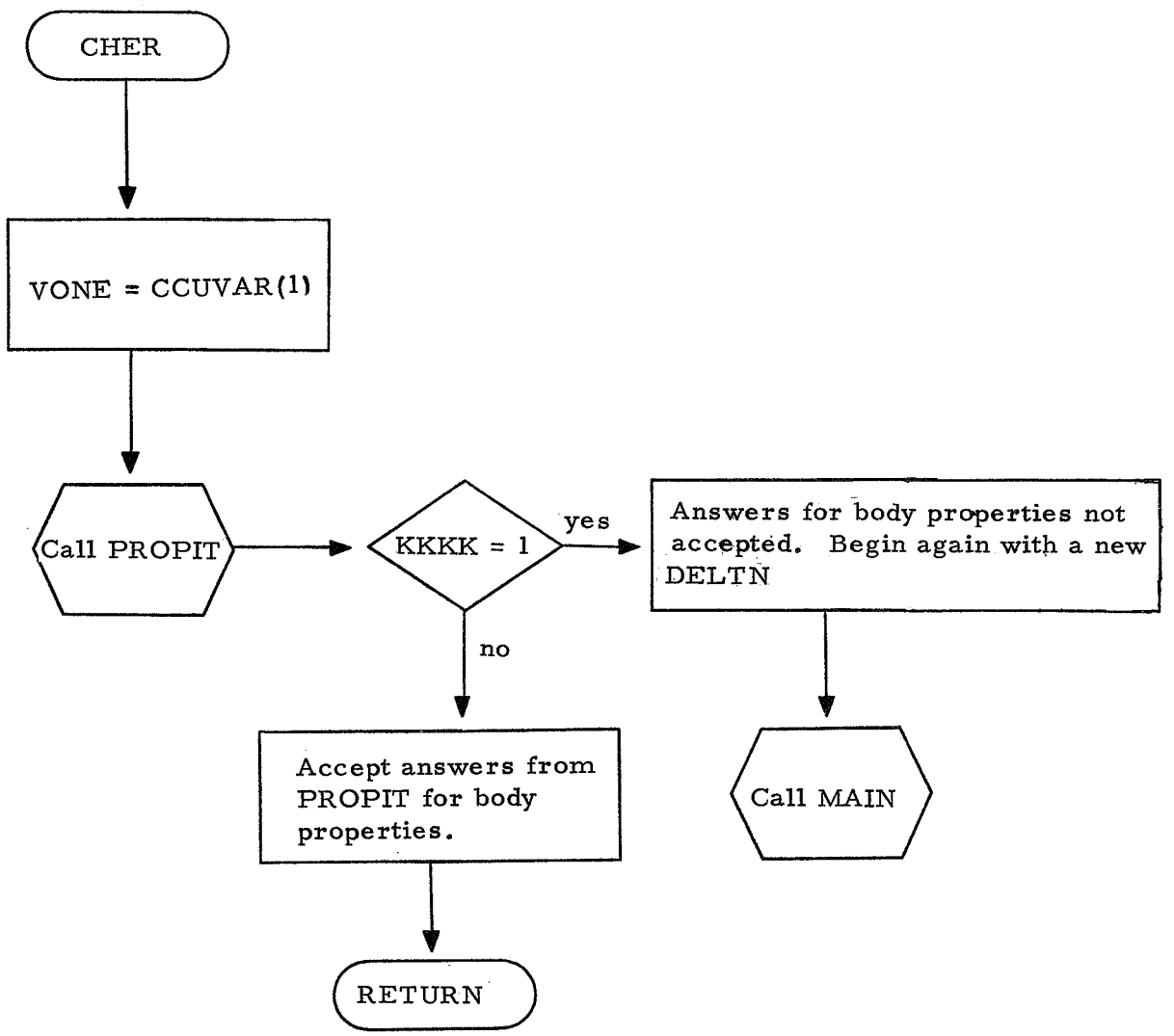
```
      SUBROUTINE CONT                                                   C    1
      DOUBLE PRECISION VVAR,CCUVAR                                      C    2
C     INPUT                                                             C    3
C                                                                       C    4
C                                                                       C    5
      COMMON /INPUTC/ R,PIN,RHOIN,UIN,EMUREF,GAMMA,RB,RBX,SMALLB,AOVERB,C    6
     1XMAX,CII,DELU,DELL,R1,Z,EPS21,NT,CCI,SSPEC,CIMAX,EELE1(7),ITEXT,IT C    7
     2TEST,TEAN,RHON,TCG,KKKK,KETEST,PIG,IGEO,EELE2(7),EELT(3)          C    8
      COMMON /EQVAR/ NE,IERR,VVAR(8),CCUVAR(8),DDER(8),ERRVAL(8),COSTB,S C    9
     1INTB,SWMTB,CWMTB,SINSQW,THETAB,SMALRB,ZB,DELS,DELTA,W,UINS,TIN,US, C   10
     2VS,U1,V1,P1,RHO1,T1,CAPH1,STAEN1,AO,UO,VO,PO,RHOO,TO,CAPHO,X,STAEN C   11
     30,STAENT,Z1,ZO,PSTAG,DAF,OPERA,DOSRB,QD,CAPQ,EO1,ICONT,ICOSW,KEKON C   12
     4T,DTBDW,DUSDW,DVSDW,DU1DW,DV1DW,DP1DW,DRO1DW,DRBDX,DTBDX,DDELDX,DW C   13
     5DX,HONE,XIO(6),XI1(6),DI1DX(6),DIODX(6),ETA,DI1DW(6),AA1(6),BB1(6) C   14
     6,GG1(6),GGO(6),CC1,DD1,SINW,COSW,KONF,PIO2,EE1(6)                 C   15
      COMMON /DDD/ DELTN                                                C   16.
      EXTERNAL DERSUB                                                   C   17
      EXTERNAL CHSUB                                                    C   18
      IT=0                                                              C   19
      VVAR(1)=X                                                         C   20
      VVAR(2)=DELTA                                                     C   21
      VVAR(3)=W                                                         C   22
      DIODX(4)=0                                                        C   23
      DO 1 KM=2,5                                                       C   24
      VVAR(KM+2)=XIO(KM)                                                C   25
1     CONTINUE                                                          C   26
C                                                                       C   27
C     IF IGEO IS EQUAL TO 2  DRBDX IS INTEGRATED                        C   28
C     NE IS THE NUMBER OF EQUATIONS TO BE INTEGRATED                    C   29
C                                                                       C   30
      IF (IGEO-2) 2,3,3                                                 C   31
2     NE=6                                                              C   32
      GO TO 4                                                           C   33
3     NE=7                                                              C   34
      VVAR(8)=SMALRB                                                    C   35
4     WRITE (6,23) (VVAR(J),J=1,8)                                      C   36
5     CALL INT1 (IT,NE,3,CCI,SSPEC,CIMAX,IERR,VVAR,CCUVAR,DDER,EELE1,EEL C   37
     1E2,EELT,ERRVAL,DERSUB,CHSUB,ITEXT)                                C   38
      IF (IGEO.GE.2) GO TO 6                                            C   39
      ZB=RB-SQRT(RB**2-SMALRB**2)                                       C   40
6     DELTROK=.1                                                        C   41
C                                                                       C   42
C     COMPUTE ETA DISTRIBUTION ONLY WHEN KEKONT = KETEST  KEKONT IS THE C   43
C     NUMBER OF PASSES  THRU MAIN.  8-31-67                             C   44
```

```
C                                                                       C  45
      IF (KEKONT-KETEST) 17,7,17                                        C  46
7     ETA=0                                                             C  47
      ITTCONT=0                                                         C  48
      KZ=Z+1                                                            C  49
      WRITE (6,24)                                                      C  50
      DO 16 K=1,KZ                                                      C  51
C                                                                       C  52
      ZE=ZB-DELTA*SIN(THETAB)*ETA                                       C  53
      SMALLR=SMALRB+DELTA*COS(THETAB)*ETA                               C  54
      EI2=XI0(2)+(XI1(2)-XI0(2))*ETA                                    C  55
      EI4=XI0(4)+(XI1(4)-XI0(4))*ETA                                    C  56
      REVES=RH00*U0**2+(RH01*U1**2-RH00*U0**2)*ETA                      C  57
      VRK=U0+(SQRT(U1**2+V1**2)-U0)*ETA                                 C  58
      VK=EI4/EI2                                                        C  59
      SUK=VRK**2-VK**2                                                  C  60
      IF (SUK) 22,8,8                                                   C  61
8     UK=SQRT(SUK)                                                      C  62
9     STAENTK=CAPH1-(UK**2+VK**2)/2.                                    C  63
      DQRUS=DELTA*CAPQ*RH00*U0**2                                       C  64
      PEK=P0+DQRUS*ETA+(P1-P0-DQRUS)*ETA**2                             C  65
C     ITERATION ON RHOK                                                 C  66
      RHOK=RHON                                                         C  67
10    CALL THEP (R,PK,RHOK,TK,ZK,STAENTK,EMUREF,PIN,RHOIN,UINS,KKKK)    C  68
      FRHOK=PK-PEK                                                      C  69
      ABSF=ABS(FRHOK)                                                   C  70
      IF (ABSF-1.E-4) 14,14,11                                          C  71
11    RHOKP=RHOK+DELTROK                                                C  72
      CALL THEP (R,PEPPK,RHOKP,TEPPK,ZEPPK,STAENTK,EMUREF,PIN,RHOIN,UINS C  73
     1,KKKK)                                                            C  74
      FPRHOK=(PEPPK-PK)/DELTROK                                         C  75
      ABFOFP=ABS(FRHOK/FPRHOK)                                          C  76
      IF (ABFOFP-1.E-4) 14,14,12                                        C  77
12    RHOK=RHOK-FRHOK/FPRHOK                                            C  78
      ITTCONT=ITTCONT+1                                                 C  79
      IF (ITTCONT-100) 10,13,13                                         C  80
13    WRITE (6,25) ETA,RHOK,STAENTK                                     C  81
      GO TO 15                                                          C  82
14    VRK=SQRT(UK**2+VK**2)                                             C  83
      WRITE (6,26) ETA,SMALLR,ZE,PK,RHOK,STAENTK,TK,ZK,UK,VK,VRK        C  84
15    ETA=ETA+1./Z                                                      C  85
16    CONTINUE                                                          C  86
C     ITERATION ON DELTN - FOR THE SPHERE                               C  87
17    PRATIO=P0/PSTAG                                                   C  88
```

```
      PCOREL=1.-1.25*SIN(X)**2+.284*SIN(X)**4                                C  89
      PDIF=PCOREL-PRATIO                                                     C  90
      WRITE (6,29) (VVAR(JK),JK=1,7),(XI1(JJ),JJ=2,5),(DDER(JL),JL=2,7),     C  91
     1(DI1DW(NL),NL=2,5),RHOO,PO,TO,ZO,VO,UO,CAPHO,SMALLR,ZE,RHO1,P1,T1,     C  92
     2Z1,V1,U1,CAPH1,STAENO,STAEN1,PRATIO,PCOREL,PDIF                        C  93
      WRITE (6,27) DRBDX                                                     C  94
      IF (IGFO.GE.2) WRITE (6,28) VVAR(8),RBX,THETAB                         C  95
      IF (IGEO.GE.2) GO TO 20                                                C  96
      IF (PDIF) 19,20,18                                                     C  97
C                                                                            C  98
C            PIG IS AN INPUT VALUE                                           C  99
C                                                                           C 100
18    IF (PDIF.LE.PIG) GO TO 20                                             C 101
      DELL=DELTN                                                            C 102
      CALL MAIN                                                             C 103
19    IF (PDIF.GE.(-.05)) GO TO 20                                          C 104
      DELU=DELTN                                                            C 105
      CALL MAIN                                                             C 106
20    IF (X-XMAX) 5,5,21                                                    C 107
21    RETURN                                                                C 108
22    UK=0                                                                  C 109
      GO TO 9                                                               C 110
C                                                                           C 111
C                                                                           C 112
23    FORMAT (1H011X44HPROPERTIES AT FIRST STEP OFF STAGNATION LINE/8X1H    C 113
     1XD15.8,5X5HDELTAD15.8,9X1HWD15.8,5X5HI0(2)D15.8,5X5HI0(3)D15.8/5X5    C 114
     2HI0(4)D15.8,5X5HI0(5)D15.8,4X6HSMALRBD15.8/)                          C 115
24    FORMAT (1H1/9X3HETA12X6HSMALLR9X2HZE13X2HP 13X4HRHO 20X19HDISTRIBU     C 116
     1TION ACROSS/9X7HSTAENT 8X2HT 13X2HZ 13X2HU 13X2HV 13X3HVR 14X11HSH    C 117
     2OCK LAYER)                                                            C 118
25    FORMAT (1H06X44HITTERATION LIMIT-REACHED IN ETA DISTRIBUTION3X3HET     C 119
     1AE15.8,2X4HRHO F15.8,2X7HSTAENT E15.8/)                               C 120
26    FORMAT (1H06X5E15.8/7X6E15.8)                                         C 121
27    FORMAT (1H06X5HDRBDXE15.8)                                            C 122
28    FORMAT (1H06X6HSMALRBD15.8,2X3HRBXE15.8,2X6HTHETABE15.8/)             C 123
29    FORMAT (1H010X25HBODY AND SHOCK PROPERTIES/8X1HXD15.8,5X5HDELTAD15     C 124
     1.8,9X1HWD15.8,5X5HI0(2)D15.8,5X5HI0(3)D15.8/5X5HI0(4)D15.8,5X5HI0(    C 125
     25)D15.8,5X5HI1(2)E15.8,5X5HI1(3)E15.8,5X5HI1(4)E15.8/5X5HI1(5)E15.    C 126
     38,5X5HDELDXE15.8,6X4HDWDXE15.8,2X8HDIODX(2)E15.8,2X8HDIODX(3)E15.8    C 127
     4/2X8HDIODX(4)E15.8,2X8HDIODX(5)E15.8,2X8HDI1DW(2)E15.8,2X8HDI1DW(3    C 128
     5)E15.8,2X8HDI1DW(4)E15.8/2X8HDI1DW(5)E15.8,25X                ,6X4HR  C 129
     6HOOE15.8,8X2HPOE15.8,8X2HTOE15.8/8X2HZOE15.8,8X2HVOE15.8,8X2HUOE15    C 130
     7.8,5X5HCAPHOE15.8,8X2HROE15.8/7X3HZE1E15.8,6X4HRHO1E15.8,8X2HP1E15    C 131
     8.8,8X2HT1E15.8,8X2HZ1E15.8/8X2HV1E15.8,8X2HU1E15.8,5X5HCAPH1E15.8,    C 132
     94X6HSTAENOE15.8,4X6HSTAEN1E15.8/4X6HPRATIOE15.8,4X6HPCORELE15.8,6X    C 133
     $4HPDIFE15.8)                                                          C 134
      END                                                                   C 135-
```

CHER

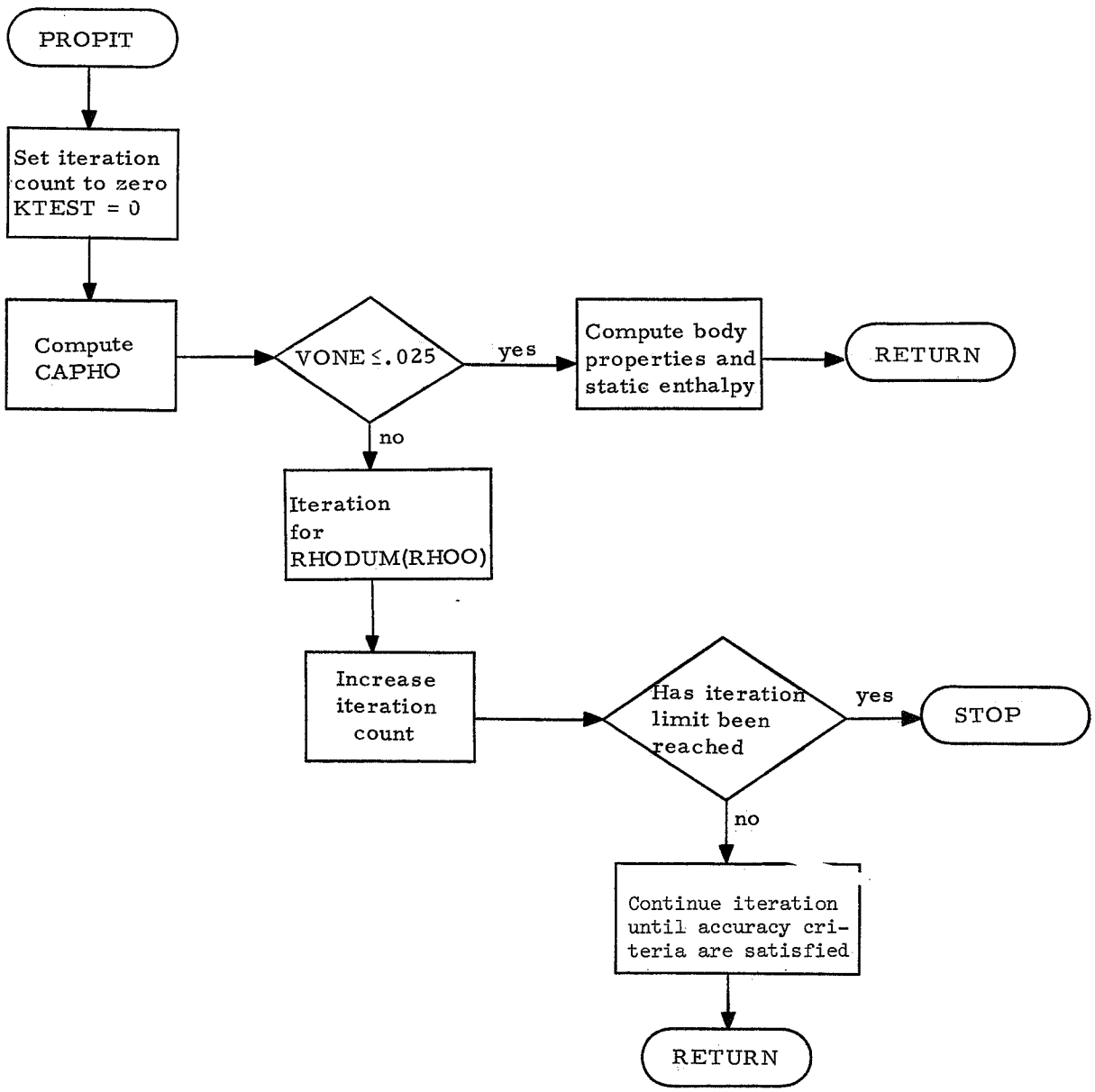
An additional test on the DELTN (δ_0) iteration is performed in CHER. After PROPIT returns to CHER, KKKK is tested. If the RHO computed in THEP is too small, KKKK (KEZ) is set to 1. When this is the case, DELL = DELTN and CHER then calls MAIN to reinitialize the program with a new DELTN. CHER is called by DERSUB. The flow chart for subprogram CHER is given below:



```
      SUBROUTINE CHER                                                   E    1
      DOUBLE PRECISION VVAR,CCUVAR                                      E    2
C     INPUT                                                             E    3
C                                                                       E    4
      COMMON /INPUTC/ R,PIN,RHOIN,UIN,EMUREF,GAMMA,RB,RBX,SMALLB,AOVERB,E    5
     1XMAX,CII,DELU,DELL,R1,Z,EPS21,NT,CCI,SSPEC,CIMAX,EELE1(7),ITEXT,IT E    6
     2TEST,TEAN,RHON,TCG,KKKK,KETEST,PIG,IGEO,EELE2(7),EELT(3)          E    7
      COMMON /FQVAR/ NE,IERR,VVAR(8),CCUVAR(8),DDER(8),ERRVAL(8),COSTB,S E    8
     1INTB,SWMTB,CWMTB,SINSQW,THETAB,SMALRB,ZB,DELS,DELTA,W,UINS,TIN,US, E    9
     2VS,U1,V1,P1,RHO1,T1,CAPH1,STAEN1,AO,UO,VO,PO,RHOO,TO,CAPHO,X,STAEN E   10
     30,STAENT,Z1,ZO,PSTAG,DAF,OPERA,DOSRB,QD,CAPQ,EO1,ICONT,ICOSW,KEKON E   11
     4T,DTBDW,DUSDW,DVSDW,DU1DW,DV1DW,DP1DW,DRO1DW,DRBDX,DTBDX,DDELDX,DW E   12
     5DX,HONE,XIO(6),XII(6),DI1DX(6),DIODX(6),ETA,DI1DW(6),AA1(6),BB1(6) E   13
     6,GG1(6),GGO(6),CC1,DD1,SINW,COSW,KONF,PIO2,EE1(6)                 E   14
      COMMON /DDD/ DELTN                                                E   15
C                                                                       E   16
C                                                                       E   17
      VONE=CCUVAR(1)                                                    E   18
      CALL PROPIT (R,UINS,XIO,TO,PO,RHOO,ITTEST,RHOIN,STAENO,ZO,KKKK,EPS E   19
     121,AO,VONE,CAPHO,UO,PIN,EMUREF)                                   E   20
      IF (KKKK.EQ.1) GO TO 1                                            E   21
      RETURN                                                            E   22
1     DELL=DELTN                                                        E   23
      CALL MAIN                                                         E   24
      END                                                               E   25-
```

PROPIT

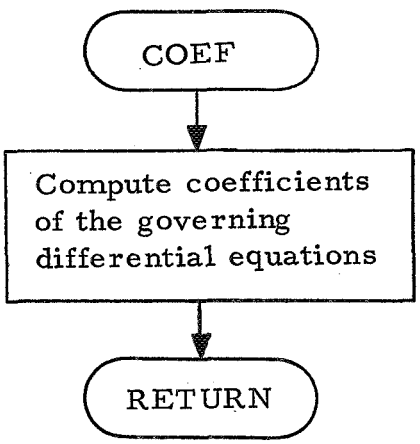
PROPIT is a subprogram called by CHER during each integration step to solve for the body properties through a Newton-Raphson iteration scheme. PROPIT has a calling sequence in which R, UINS, RHOIN, PIN, ITTEST, EPS21, and EMUREF are constants. The variables XIO, AO, and CAPHO are computed for the particular value of VONE, the independent variable X, when PROPIT is called. The body properties, PDUM, RHODUM, UGEN, TGEN, and ZDUM and the static enthalpy STAENT are computed by the subprogram. An indicator KKKK is set in THEP when RHO is too small. The flow chart for subprogram PROPIT is given below:



```
      SUBROUTINE PROPIT (R,UINS,XIO,TGEN,PDUM,RHODUM,ITTEST,RHOIN,STAENT  D    1
     1,ZDUM,KKKK,EPS21,AO,VONE,CAPHO,UGEN,PIN,EMUREF)                     D    2
      DIMENSION XIO(6)                                                    D    3
C     KTEST IS THE NUMBER OF ITTERATIONS ALLOWED ON RHO                   D    4
      KTEST=0                                                             D    5
      CAPHO=XIO(5)/XIO(2)                                                 D    6
      IF (VONE-.025) 1,1,3                                                D    7
1     UGEN=AO*VONE                                                        D    8
      STAENT=CAPHO-UGEN**2/2.                                             D    9
      RHODUM=XIO(2)/UGEN                                                  D   10
      PDUM=XIO(3)-RHODUM*UGEN**2                                          D   11
2     RETURN                                                              D   12
3     STAENT=CAPHO-.5*XIO(2)**2/RHODUM**2                                 D   13
      CALL THEP (R,PDUM,RHODUM,TGEN,ZDUM,STAENT,EMUREF,PIN,RHOIN,UINS,KK  D   14
     1KK)                                                                 D   15
      IF (KKKK.EQ.1) GO TO 7                                              D   16
      FRODUM=RHODUM-(XIO(3)-PDUM)*RHODUM**2/XIO(2)**2.                    D   17
      DELRHO=-.1                                                          D   18
      RHODMP=RHODUM+DELRHO                                                D   19
      STAD=CAPHO-.5*XIO(2)**2./RHODMP**2                                  D   20
      CALL THEP (R,PD,RHODMP,TD,ZD,STAD,EMUREF,PIN,RHOIN,UINS,KKKK)       D   21
      FPRHO=(RHODMP-(XIO(3)-PD)*RHODMP**2/XIO(2)**2.-FRODUM)/DELRHO       D   22
      FROFPR=FRODUM/FPRHO                                                 D   23
      AFRFPR=ABS(FROFPR)                                                  D   24
      IF (AFRFPR-EPS21) 6,6,4                                             D   25
4     KTEST=KTEST+1                                                       D   26
      IF (KTEST-ITTEST) 5,8,8                                             D   27
5     RHODUM=RHODUM-FROFPR                                                D   28
      GO TO 3                                                             D   29
6     UGEN=XIO(2)/RHODUM                                                  D   30
      GO TO 2                                                             D   31
7     RETURN                                                              D   32
8     WRITE (6,9)                                                         D   33
      STOP                                                                D   34
C                                                                         D   35
C                                                                         D   36
9     FORMAT (1H06X34HITTERATION LIMIT REACHED IN PROPIT)                 D   37
      END                                                                 D   38-
```

COEF

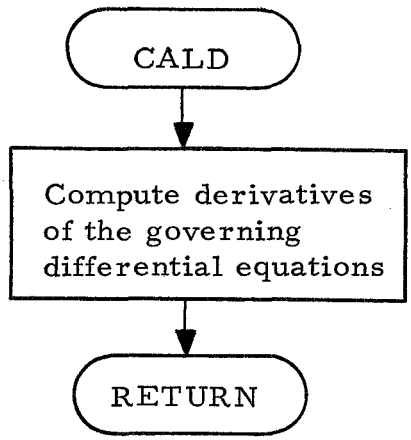
Subprogram COEF is called by DERSUB to calculate the coefficients of the governing differential equations. The flow chart for subprogram COEF is shown below:



```
      SUBROUTINE COEF                                                   K    1
      DOUBLE PRECISION VVAR,CCUVAR                                      K    2
C     INPUT                                                             K    3
      COMMON /INPUTC/ R,PIN,RHOIN,UIN,EMUREF,GAMMA,RB,RBX,SMALLB,AOVERB,K    4
     1XMAX,CII,DELU,DELL,R1,Z,EPS21,NT,CCI,SSPEC,CIMAX,EELE1(7),ITEXT,IT K    5
     2TEST,TEAN,RHON,TCG,KKKK,KETEST,PIG,IGEO,EELE2(7),EELT(3)          K    6
      COMMON /EQVAR/ NE,IERR,VVAR(8),CCUVAR(8),DDER(8),ERRVAL(8),COSTB,S K    7
     1INTB,SWMTB,CWMTB,SINSQW,THETAB,SMALRB,ZB,DELS,DELTA,W,UINS,TIN,US, K    8
     2VS,U1,V1,P1,RHO1,T1,CAPH1,STAEN1,AO,UO,VO,PO,RHOO,TO,CAPHO,X,STAEN K    9
     30,STAENT,Z1,ZO,PSTAG,DAF,OPERA,DOSRB,QD,CAPQ,EO1,ICONT,ICOSW,KEKON K   10
     4T,DTBDW,DUSDW,DVSDW,DU1DW,DV1DW,DP1DW,DRO1DW,DRBDX,DTBDX,DDELDX,DW K   11
     5DX,HONE,XIO(6),XI1(6),DI1DX(6),DIODX(6),ETA,DI1DW(6),AA1(6),BB1(6) K   12
     6,GG1(6),GGO(6),CC1,DD1,SINW,COSW,KONF,PIO2,EE1(6)                 K   13
                                                                        K   14
      CAPR1=R1                                                          K   15
                                                                        K   16
      DELS=DELTA**2                                                     K   17
      TPTOD=3.+2.*DAF                                                   K   18
      AA1(2)=3.*(XIO(2)-XI1(2))+2.*DAF*(XIO(2)-XI1(2))                  K   19
      AA1(3)=3.*(XIO(3)-XI1(3))+2.*DAF*(XIO(3)-XI1(3))                  K   20
      AA1(4)=-TPTOD*XI1(4)                                              K   21
      AA1(5)=3.*(XIO(5)-XI1(5))+2.*DAF*(XIO(5)-XI1(5))                  K   22
      DO 1 J=2,5                                                        K   23
      BB1(J)=DELTA*TPTOD*DI1DW(J)                                       K   24
    1 CONTINUE                                                          K   25
      CC1=DELTA*(3.+DAF)                                                K   26
      DD1=1.                                                            K   27
      EO1=-(1.+CAPQ*DELTA)/CAPQ*SWMTB/CWMTB*DTBDX                       K   28
      GG1(2)=RHO1*V1                                                    K   29
      GG1(3)=RHO1*U1*V1                                                 K   30
      GGO(4)=PO                                                         K   31
      GG1(4)=P1+RHO1*V1**2                                              K   32
      GG1(5)=RHO1*V1*CAPH1                                              K   33
      EE1(2)=3.*DOSRB*(XIO(2)+XI1(2))*DRBDX-DELS*OPERA*(XIO(2)+2.*XI1(2) K   34
     1)*DTBDX+6.*(1.+QD)*(1.+DAF)*GG1(2)+DELTA*TPTOD*GG1(2)*DTBDX       K   35
      EE1(3)=3.*DOSRB*(RHOO*UO**2+RHO1*U1**2)*DRBDX-DELS*OPERA*(RHOO*UO* K   36
     1*2+2.*RHO1*U1**2)*DTBDX+QD*(3.+2.*DAF)*XI1(4)+6.*(1.+QD)*(1.+DAF)* K   37
     2XI1(4)+2.*DELTA*TPTOD*XI1(4)*DTBDX                                K   38
      EE1(4)=3.*DOSRB*XI1(4)*DRBDX-2.*DELS*OPERA*XI1(4)*DTBDX-3.*(QD+DAF K   39
     1)*(XIO(3)+XI1(3))-2.*QD*DAF*(XIO(3)+2.*XI1(3))+6.*(1.+QD)*(1.+DAF) K   40
     2*GG1(4)-6.*GGO(4)+QD*DAF*(RHOO*UO**2+2.*RHO1*U1**2)+3.*DAF*(RHOO*U K   41
     30**2+RHO1*U1**2)+DELTA*(3.+2.*DAF)*RHO1*(V1**2-U1**2)*DTBDX       K   42
      EE1(5)=3.*DOSRB*(XIO(5)+XI1(5))*DRBDX-DELS*OPERA*(XIO(5)+2.*XI1(5) K   43
     1)*DTBDX+6.*(1.+QD)*(1.+DAF)*GG1(5)+6.*DELTA*R1+DELTA*(3.+2.*DAF)*G K   44
     2G1(5)*DTBDX                                                       K   45
      RETURN                                                            K   46
      END                                                               K   47-
```

CALD

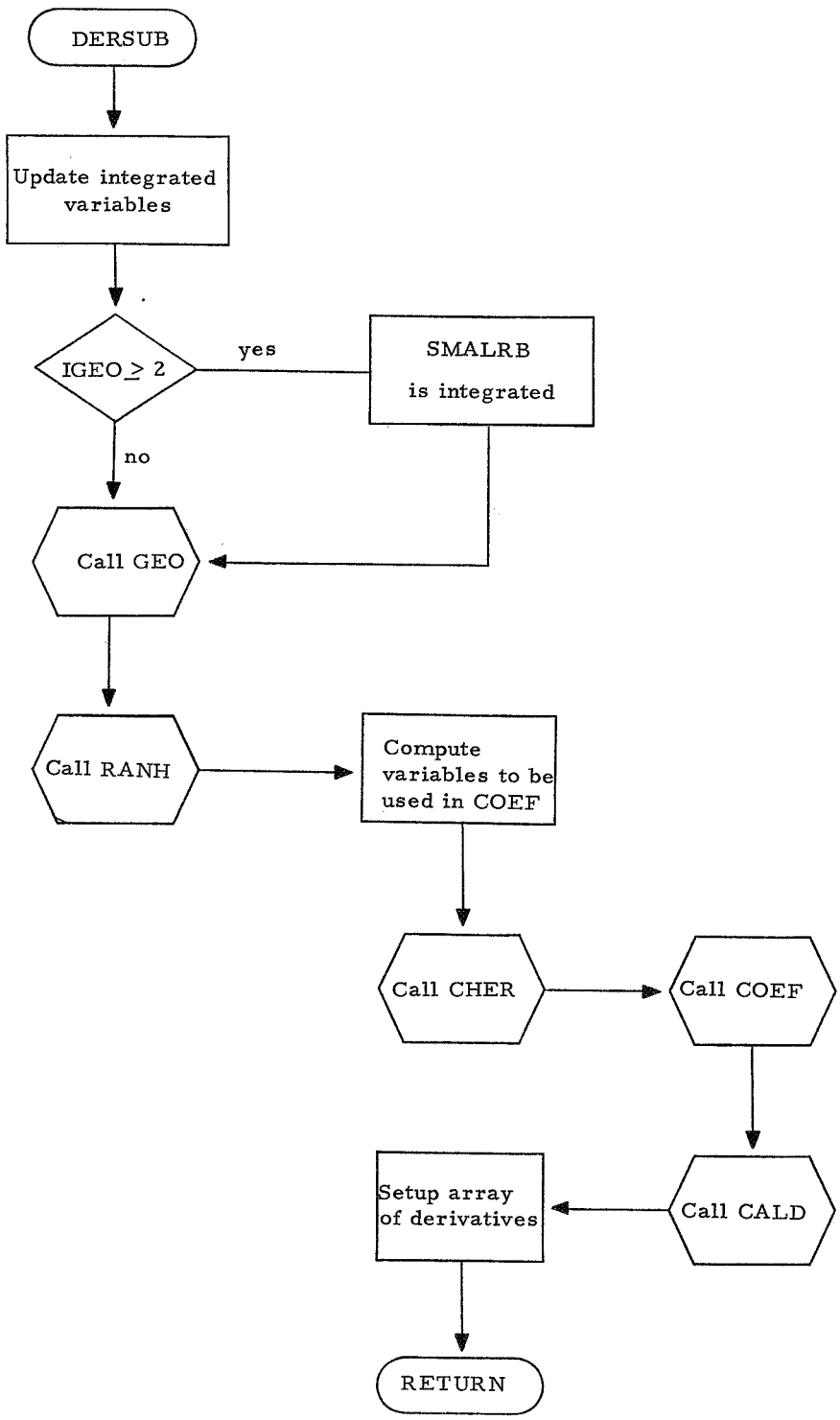
The derivatives of the governing differential equations which are used in DERSUB are computed in CALD. CALD is called by DERSUB. The flow chart for subprogram CALD is given below:



```
      SUBROUTINE CALD                                                    H    1
      DOUBLE PRECISION VVAR,CCUVAR                                       H    2
C     INPUT                                                              H    3
C                                                                        H    4
      COMMON /INPUTC/ R,PIN,RHOIN,UIN,EMUREF,GAMMA,RB,RBX,SMALLB,AOVERB, H    5
     1XMAX,CII,DELU,DELL,R1,Z,EPS21,NT,CCI,SSPEC,CIMAX,EELE1(7),ITEXT,IT H    6
     2TEST,TEAN,RHON,TCG,KKKK,KETEST,PIG,IGEO,EELE2(7),EELT(3)           H    7
      COMMON /EQVAR/ NE,IERR,VVAR(8),CCUVAR(8),DDER(8),ERRVAL(8),COSTB,S H    8
     1INTB,SWMTB,CWMTB,SINSQW,THETAB,SMALRB,ZB,DELS,DELTA,W,UINS,TIN,US, H    9
     2VS,U1,V1,P1,RHO1,T1,CAPH1,STAEN1,AO,UO,VO,PO,RHOO,TO,CAPHO,X,STAEN H   10
     30,STAENT,Z1,ZO,PSTAG,DAF,OPERA,DOSRB,QD,CAPQ,EO1,ICONT,ICOSW,KEKON H   11
     4T,DTBDW,DUSDW,DVSDW,DU1DW,DV1DW,DP1DW,DRO1DW,DRBDX,DTBDX,DDELDX,DW H   12
     5DX,HONE,XIO(6),XI1(6),DI1DX(6),DIODX(6),ETA,DI1DW(6),AA1(6),BB1(6) H   13
     6,GG1(6),GGO(6),CC1,DD1,SINW,COSW,KONF,PIO2,EE1(6)                  H   14
C                                                                        H   15
      RBS=SMALRB**2                                                      H   16
      RACE=RBS/(SMALLB**2-RBS)                                           H   17
      IF (IGEO-2) 3,1,2                                                  H   18
1     DRBDX=1./SQRT(1.+AOVERB**2*RACE)                                   H   19
      GO TO 3                                                            H   20
2     DRBDX=1./(1.+AOVERB**2*SMALRB/(SMALLB**2+RBS))                     H   21
3     DDELDX=EO1                                                         H   22
      EPS11=1.E-2                                                        H   23
      DWDX=(-AA1(4)*DDELDX-EE1(4))/BB1(4)                                H   24
      DWDXP=DWDX                                                         H   25
      DIODX(2)=(-AA1(2)*DDELDX-BB1(2)*DWDX-EE1(2))/CC1                   H   26
      DIODX(3)=UO*DIODX(2)                                               H   27
      DIODX(5)=(-AA1(5)*DDELDX-BB1(5)*DWDX-EE1(5))/CC1                   H   28
      RETURN                                                             H   29
      END                                                                H   30-
```

DERSUB

DERSUB is a subprogram used by INT1, the integration routine, to evaluate the derivatives. The flow chart for subprogram DERSUB is shown below:



```
      SUBROUTINE DERSUB                                                  J    1
      DOUBLE PRECISION VVAR,CCUVAR                                       J    2
      COMMON /INPUTC/ R,PIN,RHOIN,UIN,EMUREF,GAMMA,RB,RBX,SMALLB,AOVERB,  J    3
     1XMAX,CII,DELU,DELL,R1,Z,EPS21,NT,CCI,SSPEC,CIMAX,EELE1(7),ITEXT,IT  J    4
     2TEST,TEAN,RHON,TCG,KKKK,KETEST,PIG,IGEO,EELE2(7),EELT(3)            J    5
      COMMON /EQVAR/ NE,IERR,VVAR(8),CCUVAR(8),DDER(8),ERRVAL(8),COSTB,S  J    6
     1INTB,SWMTB,CWMTB,SINSQW,THETAB,SMALRB,ZB,DELS,DELTA,W,UINS,TIN,US,  J    7
     2VS,U1,V1,P1,RHO1,T1,CAPH1,STAEN1,AO,UO,VO,PO,RHOO,TO,CAPHO,X,STAEN  J    8
     30,STAENT,Z1,ZO,PSTAG,DAF,OPERA,DOSRB,QD,CAPQ,EO1,ICONT,ICOSW,KEKON  J    9
     4T,DTBDW,DUSDW,DVSDW,DU1DW,DV1DW,DP1DW,DRO1DW,DRBDX,DTBDX,DDELDX,DW  J   10
     5DX,HONE,XIO(6),XI1(6),DI1DX(6),DIODX(6),ETA,DI1DW(6),AA1(6),BB1(6)  J   11
     6,GG1(6),GGO(6),CC1,DD1,SINW,COSW,KONF,PIO2,EE1(6)                   J   12
C                                                                         J   13
C                                                                         J   14
      X=CCUVAR(1)                                                        J   15
      DELTA=CCUVAR(2)                                                    J   16
      W=CCUVAR(3)                                                        J   17
      XIO(2)=CCUVAR(4)                                                   J   18
      XIO(3)=CCUVAR(5)                                                   J   19
      XIO(4)=CCUVAR(6)                                                   J   20
      XIO(5)=CCUVAR(7)                                                   J   21
      IF (IGEO.GE.2) SMALRB=CCUVAR(8)                                    J   22
      CALL GEO                                                           J   23
      CALL RANH                                                          J   24
      DOSRB=DELTA/SMALRB                                                 J   25
      COSTB=COS(THETAB)                                                  J   26
      SINTB=SIN(THETAB)                                                  J   27
      DAF=DELTA*COSTB/SMALRB                                             J   28
      OPERA=SINTB/SMALRB                                                 J   29
      CALL CHER                                                          J   30
      CALL COEF                                                          J   31
      CALL CALD                                                          J   32
      DDER(2)=DDELDX                                                     J   33
      DDER(3)=DWDX                                                       J   34
      DO 1 I=2,5                                                         J   35
      DDER(I+2)=DIODX(I)                                                 J   36
1     CONTINUE                                                           J   37
      IF (IGEO.GE.2) DDER(8)=DRBDX                                       J   38
      RETURN                                                             J   39
      END                                                                J   40-
```

CHSUB

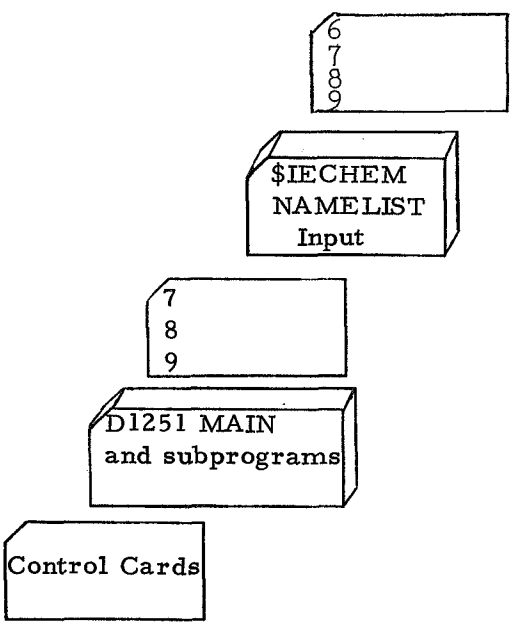
CHSUB is called by INT1. It is written by the user and is described in the appendix. In program D1251 the features of CHSUB are not needed; therefore, CHSUB is a dummy routine.

```
                SUBROUTINE CHSUB                                N   1
000002          RETURN                                          N   2
000003          END                                             N   3-
```

USAGE

Program Information and Deck Configuration

The program D1251 was written in the FORTRAN IV language for the Control Data 6600 series digital computer under the Scope 3.0 operating system. The program requires a field length of 60 000 octal locations; the computing time depends primarily on the accuracy of the initial δ_0 and the number of iterations desired, KETEST. The average time for 10 iterations on δ_0 is 1 minute per case. The following sketch shows the deck configuration needed for execution:



For the sample case $\left(U'_\infty = 1.3714 \times 10^6 \text{ cm/sec}\right.$ (45 000 ft/sec), an altitude of 60.96 km (200 000 ft), and KETEST = $\left.1\right)$, the run time was 11.37 seconds. A value of δ_0 of 0.04559 was known to be accurate from previous cases; therefore, only one iteration was needed. The results of this case are discussed in reference 1.

Input Description

The input is loaded by using the FORTRAN IV NAMELIST. The input symbols are as follows where typical values are given in parentheses:

$IECHEM

R gas constant, ergs/mole-^{o}K

PIN	free-stream pressure, dyn/cm^2
RHOIN	free-stream density, g/cm^3
UIN	free-stream velocity, cm/sec
EMUREF	molecular weight of cold air, g/mole
GAMMA	ratio of specific heats
RB	body radius at axis of symmetry x = 0, cm
RBX	body radius along the x-coordinate, nondimensionalized with RB
SMALLB	semimajor axis of an ellipse, nondimensionalized with RB
AOVERB	ratio of semiminor axis to semimajor axis of an ellipse
XMAX	limiting value in the x-direction
CII	initial linear integration step away from the singular point of the stagnation streamline; used in FIRST (.01)
DELU	upper limit for DELTA, nondimensionalized with RB
DELL	lower limit for DELTA, nondimensionalized with RB
R1	initial guess for weighted heat flux, nondimensionalized (zero in this program)
Z	number of points across shock layer where properties are desired; used in computing ETA distributions, ETA = 1./Z
EPS21	accuracy criterion used in MAIN and PROPIT for RHO iteration (.1E-5)
NT	number of values in ELT array in INT1
CCI	initial computing interval for INT1 (.01)

SSPEC	print control option for INT1
CIMAX	absolute value of maximum computing interval in INT1
EELE1	array of relative error for the dependent variables used by INT1 (1.E-5)
EELE2	array of relative zero for dependent variables used by INT1 (1.E-6)
EELT	array of NT values to return to the program from INT1 at specific values
ITEXT	time history print option for INT1; if equal to 0, no printout is requested; if equal to 1, a printout is requested
ITTEST	iteration limit in PROPIT (500)
TEAN	initial guess for T', ^{o}K
RHON	initial guess for RHO, nondimensionalized
TCG	accuracy criterion for iteration on density in RANH
KETEST	number of iterations desired on DELTN (10)
PIG	accuracy criterion for pressure in CONT (.05)
IGEO	test in GEO: 1 sphere geometry 2 ellipsoid geometry 3 hyperboloid geometry

$

Listing of Input Data for Sample Case

```
$IECHEM R=8.314395E7,PIN=225.75,RHOIN=3.153E-7,UIN=13.635E5,EMUREF=28.967,
GAMMA=1.4,RB=1,RBX=1,SMALLB=.25,AOVERB=.25,XMAX=5,CII=.01,DELU=.04459,
DELL=.04459,R1=0,Z=10,EPS21=.1E-5,NT=3,CCI=.01,SSPEC=.1,CIMAX=0,
EELE1(1)=7*1.E-5,EELE2(1)=7*1.E-6,EELT=1000,2000,3000,ITEXT=0,ITTEST=500,
TEAN=5000,RHON=14,TCG=1.E-6,KETEST=1,PIG=.05,IGEO=1$
```

Discussion of Output

The output of D1251 consists of printing only. The NAMELIST input and the first DWDX are printed in MAIN. The results from the integration routine and the ETA distribution are printed in CONT. The frequency of the output in CONT is controlled by a print option in INT1. If SSPEC is zero, control is returned to the program after every acceptable integration step. The case included in this report has a value of SSPEC equal to .1. A time history of the computing interval may be obtained by letting ITEXT be 1. The output symbols are as follows:

Properties at the first step off the stagnation line:

X	x	
DELTA	δ	
W	ω	
IO(2) - IO(5)	$I_{j,0}$	(j = 2,3,4,5)
SMALRB	r_b	

Distribution across shock layer:

The ETA distribution is computed and printed only on the last iteration on δ_o (KEKONT = KETEST).

ETA	η	
SMALLR	r	
ZE	z	
P	p	
RHO	ρ	
STAENT	h	
T	T'	

Z	Z
U	u
V	v
VR	V_R

Body and shock properties:

X	x
DELTA	δ
W	ω
IO(2) - IO(5)	$I_{j,0}$
I1(2) - I1(5)	$I_{j,1}$

$(j = 2,3,4,5)$

DELDX	$\frac{d\delta}{dx}$
DWDX	$\frac{d\omega}{dx}$
DIODX(2) - DIODX(5)	$\frac{dI_{j,0}}{dx}$
DI1DW(2) - DI1DW(5)	$\frac{\partial I_{j,1}}{\partial \omega}$
RHOO	ρ_0
PO	p_0
TO	T_0'
ZO	Z_0
VO	v_0
UO	u_0

CAPHO	H_0
RO	r_0
ZE1	z_1
RHO1	ρ_1
P1	p_1
T1	T_1'
Z1	Z_1
V1	v_1
U1	u_1
CAPH1	H_1
STAENO	h_0
STAEN1	h_1
PRATIO	$\frac{PO}{PSTAG}$
PCOREL	$1. - 1.25 \sin x^2 + .284 \sin x^4$
PDIF	PCOREL - PRATIO
DRBDX	$\frac{dr_b}{dx}$

Output for Sample Case

```
$IECHEM
R       =  0.8314395E+08,
PIN     =  0.22575E+03,
RHOIN   =  0.3153E-06,
UIN     =  0.13635E+07,
EMUREF  =  0.28967E+02,
GAMMA   =  0.14E+01,
RB      =  0.1E+01,
RBX     =  0.1E+01,
SMALLB  =  0.25E+00,
AOVERB  =  0.25E+00,
XMAX    =  0.5E+01,
CII     =  0.1E-01,
DELU    =  0.4459E-01,
DELL    =  0.4459E-01,
R1      =  0.0,
Z       =  0.1E+02,
EPS21   =  0.1E-05,
NT      =  3,
CCI     =  0.1E-01,
SSPEC   =  0.1E+00,
CIMAX   =  0.0,
EELE1   =  0.1E-04,  0.1E-04,  0.1E-04,  0.1E-04,  0.1E-04,  0.1E-04,  0.1E-04,
EELE2   =  0.1E-05,  0.1E-05,  0.1E-05,  0.1E-05,  0.1E-05,  0.1E-05,  0.1E-05,
EELT    =  0.1E+04,  0.2E+04,  0.3E+04,
```

```
ITEXT   =  0,
ITTEST  =  500,
TEAN    =  0.5E+04,
RHON    =  0.14E+02,
TCG     =  0.1E-05,
KETEST  =  1,
PIG     =  0.5E-01,
IGEO    =  1,
$END
```

```
 DWDX-7.38809558E-01

      PROPERTIES AT FIRST STEP OFF STAGNATION LINE
   X 1.00000000D-02     DELTA 4.46172837D-02          W 1.56340825D+00     IO(2) 1.15490508D-01     IO(3) 9.70700144D-01
IO(4) 0.                IO(5) 5.79036338D-02    SMALRB          IIIII
```

ETA / STAENT	SMALLR / T	ZE / Z	P / U	RHO / V	VR	DISTRIBUTION ACROSS SHOCK LAYER
0.	9.99983333E-03	4.99995833E-05	9.69909211E-01	1.68630207E+01		
5.01324457E-01	1.34678270E+04	2.76628350E+00	6.84903802E-03	0.	6.84903802E-03	
1.00000000E-01	1.00444498E-02	-4.41150570E-03	9.69607113E-01	1.68595618E+01		
5.01272220E-01	1.34670668E+04	2.76614539E+00	1.04555027E-02	-6.48583563E-03	1.23038043E-02	
2.00000000E-01	1.00890662E-02	-8.87301099E-03	9.68693758E-01	1.68467588E+01		
5.01190229E-01	1.34655873E+04	2.76594379E+00	1.22264885E-02	-1.28794336E-02	1.77585706E-02	
3.00000000E-01	1.01336826E-02	-1.33345163E-02	9.67169149E-01	1.68246046E+01		
5.01078483E-01	1.34633874E+04	2.76567875E+00	1.30721537E-02	-1.91827476E-02	2.32133369E-02	
4.00000000E-01	1.01782991E-02	-1.77960216E-02	9.65033284E-01	1.67930880E+01		
5.00936982E-01	1.34604654E+04	2.76535034E+00	1.32972990E-02	-2.53976767E-02	2.86681032E-02	
5.00000000E-01	1.02229155E-02	-2.22575268E-02	9.62286163E-01	1.67521944E+01		
5.00765727E-01	1.34568187E+04	2.76495865E+00	1.30566969E-02	-3.15260668E-02	3.41228695E-02	
6.00000000E-01	1.02675320E-02	-2.67190321E-02	9.58927787E-01	1.67019052E+01		
5.00564717E-01	1.34524443E+04	2.76450381E+00	1.24461207E-02	-3.75697130E-02	3.95776358E-02	
7.00000000E-01	1.03121484E-02	-3.11805374E-02	9.54958156E-01	1.66421983E+01		
5.00333953E-01	1.34473380E+04	2.76398599E+00	1.15336427E-02	-4.35303609E-02	4.50324021E-02	
8.00000000E-01	1.03567648E-02	-3.56420427E-02	9.50377269E-01	1.65730474E+01		
5.00073435E-01	1.34414951E+04	2.76340536E+00	1.03747218E-02	-4.94097087E-02	5.04871684E-02	
9.00000000E-01	1.04013813E-02	-4.01035480E-02	9.45185127E-01	1.64944225E+01		
4.99783162E-01	1.34349103E+04	2.76276217E+00	9.02337370E-03	-5.52094084E-02	5.59419347E-02	
1.00000000E+00	1.04459977E-02	-4.45650533E-02	9.39381729E-01	1.64062899E+01		
4.99463135E-01	1.34275770E+04	2.76205666E+00	7.54717685E-03	-6.09310677E-02	6.13967010E-02	

BODY AND SHOCK PROPERTIES

X 1.00000000D-02	DELTA 4.46172837D-02	W 1.56340825D+00	IO(2) 1.15490508D-01	IO(3) 9.70700144D-01
IO(4) 0.	IO(5) 5.79036338D-02	I1(2) 1.23821165E-01	I1(3) 9.40316183E-01	I1(4)-7.54455579E-03
I1(5) 6.20774826E-02	DELDX 2.72844670E-03	DWDX-7.33119211E-01	DIODX(2) 1.15952137E+01	DIODX(3) 7.94160593E-02
DIODX(4) 0.	DIODX(5) 5.81296512E+00	DI1DW(2)-1.54067842E+01	DI1DW(3)-2.19006014E-01	DI1DW(4) 9.39304656E-01
DI1DW(5)-7.72415908E+00		RHO0 1.68622962E+01	P0 9.69909145E-01	T0 1.34680800E+04
Z0 2.76635021E+00	V0 0.	U0 6.84903802E-03	CAPH0 5.01371367E-01	R0 1.04459977E-02
ZE1-4.45650533E-02	RH01 1.64062891E+01	P1 9.39381682E-01	T1 1.34275770E+04	Z1 2.76205666E+00
V1-6.09310677E-02	U1 7.54717685E-03	CAPH1 5.01347912E-01	STAEN0 5.01347912E-01	STAEN1 4.99463135E-01
PRATIO 1.00000000E+00	PCOREL 9.99875007E-01	PDIF-1.24992994E-04		

DRBOX 9.99950000E-01

ETA	SMALLR	ZE	P	RHO		DISTRIBUTION ACROSS
STAENT	T	Z	U	V	VR	SHOCK LAYER
0.	9.98334166E-02	4.99583472E-03	9.47627663E-01	1.65293290E+01		
4.99988761E-01	1.34387566E+04	2.76326111E+00	5.21373409E-02	0.	5.21373409E-02	
1.00000000E-01	1.00287318E-01	4.71959927E-04	9.47654129E-01	1.65391081E+01		
4.99681066E-01	1.34354469E+04	2.76238471E+00	5.69395296E-02	-9.56980694E-03	5.77381263E-02	
2.00000000E-01	1.00741219E-01	-4.05191487E-03	9.47324953E-01	1.65438571E+01		
4.99342003E-01	1.34315591E+04	2.76143157E+00	6.07443268E-02	-1.79428120E-02	6.33389118E-02	
3.00000000E-01	1.01195121E-01	-8.57578966E-03	9.46640135E-01	1.65435673E+01		
4.98971571E-01	1.34270924E+04	2.76040166E+00	6.41175263E-02	-2.53303113E-02	6.89396972E-02	
4.00000000E-01	1.01649022E-01	-1.30996645E-02	9.45599676E-01	1.65382281E+01		
4.98569770E-01	1.34220457E+04	2.75929498E+00	6.73712758E-02	-3.18966260E-02	7.45404826E-02	
5.00000000E-01	1.02102924E-01	-1.76235393E-02	9.44203576E-01	1.65278269E+01		
4.98136601E-01	1.34164175E+04	2.75811155E+00	7.06819563E-02	-3.77714694E-02	8.01412681E-02	
6.00000000E-01	1.02556825E-01	-2.21474140E-02	9.42451834E-01	1.65123490E+01		
4.97672062E-01	1.34102063E+04	2.75685137E+00	7.41461834E-02	-4.30586022E-02	8.57420535E-02	
7.00000000E-01	1.03010726E-01	-2.66712888E-02	9.40344450E-01	1.64917777E+01		
4.97176155E-01	1.34034101E+04	2.75551446E+00	7.78116697E-02	-4.78420138E-02	9.13428390E-02	
8.00000000E-01	1.03464628E-01	-3.11951636E-02	9.37881425E-01	1.64660943E+01		
4.96648879E-01	1.33960267E+04	2.75410085E+00	8.16959401E-02	-5.21904176E-02	9.69436244E-02	
9.00000000E-01	1.03918529E-01	-3.57190384E-02	9.35062759E-01	1.64352780E+01		
4.96090234E-01	1.33880534E+04	2.75261059E+00	8.57982871E-02	-5.61605727E-02	1.02544410E-01	
1.00000000E+00	1.04372431E-01	-4.02429132E-02	9.31888451E-01	1.63993058E+01		
4.95500220E-01	1.33794875E+04	2.75104373E+00	9.01075476E-02	-5.97997753E-02	1.08145195E-01	

BODY AND SHOCK PROPERTIES

X 1.000000000D-01	DELTA 4.54658879D-02	W 1.48119568D+00	IO(2) 8.61794726D-01	IO(3) 9.92559294D-01	
IO(4) 0.	IO(5) 4.32059253D-01	I1(2) 1.47770116E+00	I1(3) 1.06504043E+00	I1(4)-8.83661972E-02	
I1(5) 7.40842390E-01	DELDX 1.08725325E-02	DWDX-1.03670213E+00	DIODX(2) 5.80970564E+00	DIODX(3) 3.02902603E-01	
DIODX(4) 0.	DIODX(5) 2.91268107E+00	DI1DW(2)-1.54484636E+01	DI1DW(3)-2.61187858E+00	DI1DW(4) 1.03323808E+00	
DI1DW(5)-7.74505498E+00		RHO0 1.65293187E+01	P0 9.47627611E-01	T0 1.34387599E+04	
Z0 2.76326199E+00	V0 0.	U0 5.21373409E-02	CAPH0 5.01348221E-01	R0 1.04372431E-01	
ZE1-4.02429132E-02	RHO1 1.63993050E+01	P1 9.31888404E-01	T1 1.33794875E+04	Z1 2.75104373E+00	
V1-5.97997753E-02	U1 9.01075476E-02	CAPH1 5.01347912E-01	STAENO 4.99989070E-01	STAEN1 4.95500220E-01	
PRATIO 9.77027195E-01	PCOREL 9.87569822E-01	PDIF 1.05426271E-02			

DRBDX 9.95004165E-01

ETA / STAENT	SMALLR / T	ZE / Z	P / U	RHO / V	VR	DISTRIBUTION ACROSS SHOCK LAYER
0.	1.98669331E-01	1.99334222E-02	9.06151539E-01	1.59050950E+01		
4.97430959E-01	1.33829832E+04	2.75746583E+00	8.85093529E-02	0.	8.85093529E-02	
1.00000000E-01	1.99590710E-01	1.53881162E-02	9.06659992E-01	1.59446526E+01		
4.96378312E-01	1.33718987E+04	2.75444952E+00	9.90171786E-02	-1.16102544E-02	9.96955348E-02	
2.00000000E-01	2.00512089E-01	1.08428103E-02	9.07029631E-01	1.59857120E+01		
4.95200534E-01	1.33593234E+04	2.75108198E+00	1.08888490E-01	-2.09296896E-02	1.10881717E-01	
3.00000000E-01	2.01433468E-01	6.29750438E-03	9.07260457E-01	1.60283139E+01		
4.93897626E-01	1.33452456E+04	2.74736322E+00	1.18676101E-01	-2.85754260E-02	1.22067899E-01	
4.00000000E-01	2.02354847E-01	1.75219845E-03	9.07352468E-01	1.60725019E+01		
4.92469587E-01	1.33296520E+04	2.74329325E+00	1.28586023E-01	-3.49611878E-02	1.33254081E-01	
5.00000000E-01	2.03276226E-01	-2.79310747E-03	9.07305665E-01	1.61183225E+01		
4.90916417E-01	1.33125281E+04	2.73887210E+00	1.38682628E-01	-4.03747207E-02	1.44440262E-01	
6.00000000E-01	2.04197605E-01	-7.33841340E-03	9.07120047E-01	1.61658253E+01		
4.89238117E-01	1.32938577E+04	2.73409982E+00	1.48971736E-01	-4.50223503E-02	1.55626444E-01	
7.00000000E-01	2.05118984E-01	-1.18837193E-02	9.06795616E-01	1.62150631E+01		
4.87434686E-01	1.32736232E+04	2.72897647E+00	1.59436424E-01	-4.90558775E-02	1.66812626E-01	
8.00000000E-01	2.06040363E-01	-1.64290253E-02	9.06332371E-01	1.62660922E+01		
4.85506124E-01	1.32518052E+04	2.72350218E+00	1.70052706E-01	-5.25894737E-02	1.77998808E-01	
9.00000000E-01	2.06961742E-01	-2.09743312E-02	9.05730312E-01	1.63189725E+01		
4.83452432E-01	1.32283826E+04	2.71767708E+00	1.80796247E-01	-5.57106600E-02	1.89184990E-01	
1.00000000E+00	2.07883121E-01	-2.55196371E-02	9.04989438E-01	1.63737677E+01		
4.81273609E-01	1.32033326E+04	2.71150136E+00	1.91644986E-01	-5.84876548E-02	2.00371172E-01	

BODY AND SHOCK PROPERTIES

X 2.00000000D-01	DELTA 4.63775218D-02	W 1.37841825D+00	IO(2) 1.40774938D+00	IO(3) 1.03075047D+00	
IO(4) 0.	IO(5) 7.05772342D-01	I1(2) 3.13795035E+00	I1(3) 1.50636185E+00	I1(4)-1.83531357E-01	
I1(5) 1.57320485E+00	DELDX 7.97554311E-03	DWDX-1.00840482E+00	DIODX(2) 5.26876816E+00	DIODX(3) 4.66335260E-01	
DIODX(4) 0.	DIODX(5) 2.64148524E+00	DI1DW(2)-1.55607685E+01	DI1DW(3)-5.53429681E+00	DI1DW(4) 1.44972661E+00	
DI1DW(5)-7.80135880E+00		RHOO 1.59050917E+01	PO 9.06151510E-01	TO 1.33829842E+04	
ZO 2.75746610E+00	VO 0.	UO 8.85093529E-02	CAPHO 5.01348005E-01	RO 2.07883121E-01	
ZE1-2.55196371E-02	RHO1 1.63737670E+01	P1 9.04989394E-01	T1 1.32033326E+04	Z1 2.71150136E+00	
V1-5.84876548E-02	U1 1.91644986E-01	CAPH1 5.01347912E-01	STAENO 4.97431052E-01	STAEN1 4.81273609E-01	
PRATIO 9.34264322E-01	PCOREL 9.51105548E-01	PDIF 1.68412262E-02			

DRBDX 9.80066578E-01

ETA / STAENT	SMALLR / T	ZE / Z	P / U	RHO / V	VR	DISTRIBUTION ACROSS SHOCK LAYER
0.	2.95520207E-01	4.46635109E-02	8.42172019E-01	1.49341696E+01		
4.93276758E-01	1.32922124E+04	2.74802681E+00	1.27052381E-01	0.	1.27052381E-01	
1.00000000E-01	2.96914700E-01	4.01554934E-02	8.43401007E-01	1.50181026E+01		
4.91024276E-01	1.32684600E+04	2.74155546E+00	1.43177323E-01	-1.21460222E-02	1.43691585E-01	
2.00000000E-01	2.98309193E-01	3.56474758E-02	8.44793632E-01	1.51134426E+01		
4.88494931E-01	1.32416254E+04	2.73428915E+00	1.58880070E-01	-2.15194279E-02	1.60330790E-01	
3.00000000E-01	2.99703686E-01	3.11394583E-02	8.46350327E-01	1.52205202E+01		
4.85688722E-01	1.32116461E+04	2.72622846E+00	1.74582311E-01	-2.89723324E-02	1.76969995E-01	
4.00000000E-01	3.01098179E-01	2.66314408E-02	8.47953539E-01	1.53376515E+01		
4.82605651E-01	1.31783654E+04	2.71737862E+00	1.90411954E-01	-3.50401209E-02	1.93609200E-01	
5.00000000E-01	3.02492672E-01	2.21234233E-02	8.49815871E-01	1.54689498E+01		
4.79245716E-01	1.31418566E+04	2.70773269E+00	2.06393552E-01	-4.00760968E-02	2.10248405E-01	
6.00000000E-01	3.03887165E-01	1.76154057E-02	8.51839279E-01	1.56131809E+01		
4.75608918E-01	1.31019578E+04	2.69729582E+00	2.22516235E-01	-4.43228223E-02	2.26887610E-01	
7.00000000E-01	3.05281658E-01	1.31073882E-02	8.54023762E-01	1.57708691E+01		
4.71695257E-01	1.30585673E+04	2.68606984E+00	2.38759044E-01	-4.79523547E-02	2.43526815E-01	
8.00000000E-01	3.06676152E-01	8.59937068E-03	8.56369322E-01	1.59426007E+01		
4.67504733E-01	1.30115717E+04	2.67405711E+00	2.55100288E-01	-5.10901277E-02	2.60166020E-01	
9.00000000E-01	3.08070645E-01	4.09135316E-03	8.58875958E-01	1.61290296E+01		
4.63037346E-01	1.29608448E+04	2.66126059E+00	2.71520701E-01	-5.38297420E-02	2.76805225E-01	
1.00000000E+00	3.09465138E-01	-4.16664363E-04	8.61543670E-01	1.63308845E+01		
4.58293095E-01	1.29062464E+04	2.64768394E+00	2.88004199E-01	-5.62424609E-02	2.93444430E-01	

BODY AND SHOCK PROPERTIES

X 3.00000000D-01	DELTA 4.71877453D-02	W 1.27915566D+00	IO(2) 1.89729755D+00	IO(3) 1.08317113D+00	
IO(4) 0.	IO(5) 9.51206253D-01	I1(2) 4.70336311E+00	I1(3) 2.21613196E+00	I1(4)-2.64528715E-01	
I1(5) 2.35802127E+00	DELDX 8.75397583E-03	DWDX-9.77646382E-01	DIODX(2) 4.40867906E+00	DIODX(3) 5.60133170E-01	
DIODX(4) 0.	DIODX(5) 2.21028175E+00	DI1DW(2)-1.57559985E+01	DI1DW(3)-8.27247614E+00	DI1DW(4) 2.11656168E+00	
DI1DW(5)-7.89923695E+00		RHOO 1.49331917E+01	PO 8.42114963E-01	TO 1.32921709E+04	
ZO 2.74802914E+00	VO 0.	UO 1.27052381E-01	CAPHO 5.01347958E-01	RO 3.09465138E-01	
ZE1-4.16664363E-04	RHO1 1.63308838E+01	P1 8.61543630E-01	T1 1.29062464E+04	Z1 2.64768394E+00	
V1-5.62424609E-02	U1 2.88004199E-01	CAPH1 5.01347912E-01	STAENO 4.93276804E-01	STAEN1 4.58293095E-01	
PRATIO 8.68241080E-01	PCOREL 8.93000802E-01	PDIF 2.47597222E-02			

DRBDX 9.55336489E-01

ETA	SMALLR	ZE	P	RHO		DISTRIBUTION ACROSS
STAENT	T	Z	U	V	VR	SHOCK LAYER
0.	3.89418342E-01	7.89390060E-02	7.60802512E-01	1.36836927E+01		
4.87590191E-01	1.31673989E+04	2.73506177E+00	1.65877794E-01	0.	1.65877794E-01	
1.00000000E-01	3.91297231E-01	7.44950153E-02	7.62874019E-01	1.38188955E+01		
4.83772784E-01	1.31268353E+04	2.72406813E+00	1.87095382E-01	-1.20653858E-02	1.87484014E-01	
2.00000000E-01	3.93176120E-01	7.00510245E-02	7.65469957E-01	1.39778345E+01		
4.79488549E-01	1.30810133E+04	2.71172331E+00	2.08027669E-01	-2.10526689E-02	2.09090234E-01	
3.00000000E-01	3.95055009E-01	6.56070338E-02	7.68591896E-01	1.41615841E+01		
4.74737485E-01	1.30297358E+04	2.69803054E+00	2.28990151E-01	-2.80065139E-02	2.30696454E-01	
4.00000000E-01	3.96933898E-01	6.11630431E-02	7.72241664E-01	1.43714019E+01		
4.69519592E-01	1.29727740E+04	2.68299429E+00	2.50062482E-01	-3.35469033E-02	2.52302674E-01	
5.00000000E-01	3.98812787E-01	5.67190523E-02	7.76421356E-01	1.46087509E+01		
4.63834871E-01	1.29098640E+04	2.66662059E+00	2.71251057E-01	-3.80650330E-02	2.73908895E-01	
6.00000000E-01	4.00691676E-01	5.22750616E-02	7.81133361E-01	1.48753252E+01		
4.57683321E-01	1.28407028E+04	2.64891747E+00	2.92541067E-01	-4.18199326E-02	2.95515115E-01	
7.00000000E-01	4.02570565E-01	4.78310709E-02	7.86380379E-01	1.51730818E+01		
4.51064942E-01	1.27649435E+04	2.62989542E+00	3.13913757E-01	-4.49899339E-02	3.17121335E-01	
8.00000000E-01	4.04449455E-01	4.33870801E-02	7.92027246E-01	1.55016675E+01		
4.43979734E-01	1.26820872E+04	2.60957314E+00	3.35351893E-01	-4.77018257E-02	3.38727555E-01	
9.00000000E-01	4.06328344E-01	3.89430894E-02	7.98280252E-01	1.58674574E+01		
4.36427697E-01	1.25918321E+04	2.58796041E+00	3.56841148E-01	-5.00482211E-02	3.60333775E-01	
1.00000000E+00	4.08207233E-01	3.44990987E-02	8.05055189E-01	1.62717923E+01		
4.28408832E-01	1.24935943E+04	2.56508269E+00	3.78370086E-01	-5.20983450E-02	3.81939995E-01	

BODY AND SHOCK PROPERTIES

X 4.00000000D-01	DELTA 4.82486037D-02	W 1.18350995D+00	IO(2) 2.26979240D+00	IO(3) 1.13730086D+00	
IO(4) 0.	IO(5) 1.13795575D+00	I1(2) 6.15675920E+00	I1(3) 3.13458866E+00	I1(4)-3.20756965E-01	
I1(5) 3.08667837E+00	DELDX 1.33277266E-02	DWDX-9.26866504E-01	DIODX(2) 2.95374566E+00	DIODX(3) 4.89960815E-01	
DIODX(4) 0.	DIODX(5) 1.48085405E+00	DI1DW(2)-1.60550412E+01	DI1DW(3)-1.08117434E+01	DI1DW(4) 2.94416661E+00	
DI1DW(5)-8.04916137E+00		RHOO 1.36835217E+01	PO 7.60792703E-01	TO 1.31673913E+04	
ZO 2.73506226E+00	VO 0.	UO 1.65877794E-01	CAPHO 5.01347940E-01	RO 4.08207233E-01	
ZE1 3.44990987E-02	RHO1 1.62717916E+01	P1 8.05055153E-01	T1 1.24935942E+04	Z1 2.56508269E+00	
V1-5.20983450E-02	U1 3.78370086E-01	CAPH1 5.01347912E-01	STAENO 4.87590219E-01	STAEN1 4.28408832E-01	
PRATIO 7.84395845E-01	PCOREL 8.16972758E-01	PDIF 3.25769130E-02			

DRBDX 9.21060994E-01

ETA	SMALLR	ZE	P	RHO		DISTRIBUTION ACROSS
STAENT	T	Z	U	V	VR	SHOCK LAYER
0.	4.79425539E-01	1.22417438E-01	6.83840324E-01	1.24833605E+01		
4.81705080E-01	1.30376724E+04	2.72158333E+00	1.98206117E-01	0.	1.98206117E-01	
1.00000000E-01	4.81831184E-01	1.18013934E-01	6.86655218E-01	1.26658284E+01		
4.76196885E-01	1.29785336E+04	2.70568982E+00	2.24028352E-01	-1.06466995E-02	2.24281195E-01	
2.00000000E-01	4.84236829E-01	1.13610430E-01	6.90277810E-01	1.28839314E+01		
4.70008780E-01	1.29113816E+04	2.68782691E+00	2.49689504E-01	-1.82596604E-02	2.50356273E-01	
3.00000000E-01	4.86642474E-01	1.09206926E-01	6.94469527E-01	1.31355600E+01		
4.63140766E-01	1.28355606E+04	2.66801500E+00	2.75389807E-01	-2.39738583E-02	2.76431351E-01	
4.00000000E-01	4.89048119E-01	1.04803422E-01	6.99376323E-01	1.34259123E+01		
4.55592842E-01	1.27506659E+04	2.64626151E+00	3.01168379E-01	-2.84208904E-02	3.02506429E-01	
5.00000000E-01	4.91453764E-01	1.00399918E-01	7.05002519E-01	1.37581641E+01		
4.47365009E-01	1.26560743E+04	2.62258560E+00	3.27021519E-01	-3.19801908E-02	3.28581507E-01	
6.00000000E-01	4.93859409E-01	9.59964143E-02	7.11353110E-01	1.41360924E+01		
4.38457266E-01	1.25510531E+04	2.59701344E+00	3.52935886E-01	-3.48934535E-02	3.54656584E-01	
7.00000000E-01	4.96265054E-01	9.15929103E-02	7.18433842E-01	1.45641910E+01		
4.28869613E-01	1.24347404E+04	2.56958031E+00	3.78897970E-01	-3.73219345E-02	3.80731662E-01	
8.00000000E-01	4.98670699E-01	8.71894063E-02	7.26251315E-01	1.50478173E+01		
4.18602050E-01	1.23061220E+04	2.54033338E+00	4.04896466E-01	-3.93773444E-02	4.06806740E-01	
9.00000000E-01	5.01076344E-01	8.27859024E-02	7.34669815E-01	1.55904442E+01		
4.07654578E-01	1.21638946E+04	2.50934031E+00	4.30922508E-01	-4.11395194E-02	4.32881818E-01	
1.00000000E+00	5.03481989E-01	7.83823984E-02	7.43858578E-01	1.62029156E+01		
3.96027196E-01	1.20067719E+04	2.47667748E+00	4.56969317E-01	-4.26670329E-02	4.58956896E-01	

BODY AND SHOCK PROPERTIES

X 5.00000000D-01	DELTA 5.01776597D-02	W 1.09768624D+00	IO(2) 2.47427823D+00	IO(3) 1.17425738D+00	
IO(4) 0.	IO(5) 1.24047427D+00	I1(2) 7.40423495E+00	I1(3) 4.12736673E+00	I1(4)-3.15916736E-01	
I1(5) 3.71209773E+00	DELDX 2.82459721E-02	DWDX-7.51575177E-01	DIODX(2) 1.10310189E+00	DIODX(3) 2.18641542E-01	
DIODX(4) 0.	DIODX(5) 5.53037707E-01	DI1DW(2)-1.64929644E+01	DI1DW(3)-1.30607585E+01	DI1DW(4) 3.69244048E+00	
DI1DW(5)-8.26871328E+00		RHOO 1.24833596E+01	PO 6.83840297E-01	TO 1.30376726E+04	
ZO 2.72158339E+00	VO 0.	UO 1.98206117E-01	CAPHO 5.01347932E-01	RO 5.03481989E-01	
ZE1 7.83823984E-02	RHO1 1.62029149E+01	P1 7.43858547E-01	T1 1.20067718E+04	Z1 2.47667748E+00	
V1-4.26670329E-02	U1 4.56969317E-01	CAPH1 5.01347912E-01	STAENO 4.81705100E-01	STAEN1 3.96027196E-01	
PRATIO 7.05056036E-01	PCOREL 7.27692801E-01	PDIF 2.26367649E-02			

DRBDX 8.77582562E-01

ETA	SMALLR	ZE	P	RHO		DISTRIBUTION ACROSS
STAENT	T	Z	U	V	VR	SHOCK LAYER
0.	5.64642473E-01	1.74664385E-01	6.76138669E-01	1.23622177E+01		
4.81085112E-01	1.30239721E+04	2.72015991E+00	2.01309709E-01	0.	2.01309709E-01	
1.00000000E-01	5.67752812E-01	1.70118016E-01	6.78894717E-01	1.25675976E+01		
4.74545524E-01	1.29531006E+04	2.70131314E+00	2.31489863E-01	-4.14969966E-03	2.31527054E-01	
2.00000000E-01	5.70863150E-01	1.65571647E-01	6.81643504E-01	1.28011842E+01		
4.67092847E-01	1.28703923E+04	2.67987093E+00	2.61650644E-01	-7.00501156E-03	2.61744398E-01	
3.00000000E-01	5.73973488E-01	1.61025278E-01	6.84453783E-01	1.30668882E+01		
4.58727083E-01	1.27752021E+04	2.65584473E+00	2.91820208E-01	-9.08984966E-03	2.91961742E-01	
4.00000000E-01	5.77083827E-01	1.56478908E-01	6.87151742E-01	1.33647036E+01		
4.49448230E-01	1.26665282E+04	2.62926423E+00	3.22002054E-01	-1.06789961E-02	3.22179087E-01	
5.00000000E-01	5.80194165E-01	1.51932539E-01	6.89854368E-01	1.37006007E+01		
4.39256290E-01	1.25434423E+04	2.60015705E+00	3.52194419E-01	-1.19304513E-02	3.52396431E-01	
6.00000000E-01	5.83304503E-01	1.47386170E-01	6.92565946E-01	1.40793216E+01		
4.28151261E-01	1.24047044E+04	2.56857050E+00	3.82394846E-01	-1.29415157E-02	3.82613775E-01	
7.00000000E-01	5.86414842E-01	1.42839801E-01	6.95291496E-01	1.45066365E+01		
4.16133145E-01	1.22488148E+04	2.53457198E+00	4.12601227E-01	-1.37753842E-02	4.12831120E-01	
8.00000000E-01	5.89525180E-01	1.38293432E-01	6.98036924E-01	1.49896111E+01		
4.03201941E-01	1.20739551E+04	2.49825624E+00	4.42811946E-01	-1.44748861E-02	4.43048464E-01	
9.00000000E-01	5.92635518E-01	1.33747063E-01	7.00681745E-01	1.55342394E+01		
3.89357649E-01	1.18778157E+04	2.45975998E+00	4.73025811E-01	-1.50700768E-02	4.73265808E-01	
1.00000000E+00	5.95745857E-01	1.29200693E-01	7.03372462E-01	1.61541589E+01		
3.74600270E-01	1.16578040E+04	2.41926124E+00	5.03241955E-01	-1.55826701E-02	5.03483153E-01	

BODY AND SHOCK PROPERTIES

X 6.000000000-01	DELTA 5.50850953D-02	W 1.04647774D+00	IO(2) 2.48863427D+00	IO(3) 1.17712488D+00	
IO(4) 0.	IO(5) 1.24767163D+00	I1(2) 8.12945016E+00	I1(3) 4.79445283E+00	I1(4)-1.26678540E-01	
I1(5) 4.07568287E+00	DELDX 8.00031057E-02	DWDX-1.86080688E-01	DIODX(2)-8.99204139E-01	DIODX(3)-1.81018524E-01	
DIODX(4) 0.	DIODX(5)-4.50814231E-01	DI1DW(2)-1.70988572E+01	DI1DW(3)-1.46820839E+01	DI1DW(4) 3.56282328E+00	
DI1DW(5)-8.57247634E+00		RHOO 1.23622168E+01	PO 6.76138636E-01	TO 1.30239723E+04	
ZO 2.72015995E+00	VO 0.	UO 2.01309709E-01	CAPHO 5.01347928E-01	RO 5.95745857E-01	
ZE1 1.29200693E-01	RHO1 1.61541582E+01	P1 7.03372433E-01	T1 1.16578040E+04	Z1 2.41926124E+00	
V1-1.55826701E-02	U1 5.03241955E-01	CAPH1 5.01347912E-01	STAENO 4.81085128E-01	STAEN1 3.74600270E-01	
PRATIO 6.97115436E-01	PCOREL 6.30341319E-01	PDIF-6.67741177E-02			

DRBDX 8.25335615E-01
DWDX-7.38809558E-01

```
03/19/70   LRC CM SCOPE 3.0  6600C-131K 02/24/70
16.51.31.DAP3319.          -   319  1549
16.51.31.                      LRC COMPUTER COMPLEX
16.51.31.JOB,1,400,70000.            D1250,31328,1,
16.51.31.FRANCES W TAYLOR          ,2040B
16.51.31.RUN(S)
16.51.41.LINECNT(10000)
16.51.41.SETINDF.
16.51.42.LGO.
16.51.53.MEMORY  023100 CM
16.52.10.STOP
16.52.11.SPPRINT(OUTPUT,5)
16.52.12.CPU     11.605384 SEC.
16.52.12.PPU     18.792448 SEC.
16.52.12.DATE      03/19/70
17.04.48. DAP3319. PRINT-PP 01744 LINES,LP 25
```

Error Diagnostics

The following table gives the error diagnostics as the message and the corresponding subprogram which prints the message:

Message	Diagnosis	Subprogram
RHO is smaller than allowed	Nonfatal	THEP
	Fatal	THER
RHO is larger than allowed	Fatal	THEP, THER
H is zero or negative	Fatal	THEP, THER
H is larger than allowed	Fatal	THEP, THER
Iteration limit reached in ETA distribution	Nonfatal	CONT
Iteration limit reached in PROPIT	Fatal	PROPIT

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., April 17, 1970.

APPENDIX

SUBROUTINE INT1

Language: FORTRAN

Purpose: To solve a set of ordinary differential equations.

Use: CALL INT1 (II,N,NT,CI,SPEC,CIMAX,IERR,VAR,CUVAR,DER,ELE1,ELE2,ELT, ERRVAL,DERSUB,CHSUB,ITEXT)

II — INT1 is a closed subroutine composed of an initialization section and an integration section. The user is required to enter the initialization section before he starts his first integration step. The above calling sequence is used for both initialization and integration, with the value of the code word II determining which of the two sections of INT1 will be entered.

The user must set II = 0 in order to initialize.

During initialization the derivatives will be evaluated by using the initial values of the variables, but no integration will occur and control will be returned to the calling program. When INT1 is called with II > 0, entry is made to the integration section. Upon each entry to INT1, the subroutine stores a 1 in II so that the user need not supply a value of II > 0 for repetitive integration.

Besides serving as a means for specifying the entry point to INT1 from the calling program, II can also be set to specified values in CHSUB:

2 The user will store the integer 2 in II if the answers in CHSUB are not acceptable to him and he wishes to recompute the answers using a shorter interval. This shorter interval must be stored by the user in CI. It must be smaller than the computing interval just used.

3 The user will store the integer 3 in II if he wishes to return to the calling program. The answers for the interval are considered acceptable to the user and will be transferred to the VAR array (explained below) by INT1.

In DERSUB II may be set to:

4 The user will store the integer 4 in II if he wishes to discontinue calculation of the present interval and return to the calling

program. On return to the calling program, the answers at the beginning of the interval will still be in the VAR array.

If the user does not set II to a value in either CHSUB or DERSUB, II will always be 1 upon the return to the calling program.

N — An integer value supplied by the user which is the number of differential equations to be solved. INT1 is compiled to solve a maximum of 20 equations but may be recompiled for larger values of N if necessary.

NT — An integer value supplied by the user which is the number of values in the ELT block described later in this writeup. INT1 is compiled with a maximum of 10 values in the ELT block but may be recompiled for more values if necessary.

CI — A floating-point value supplied by the user which is the computing interval that INT1 will use initially. CI must be a signed value – positive if integrating forward, negative if integrating backward. Upon entry to CHSUB, CI will contain the computing interval that INT1 will use for the next step unless it has to take a short interval to hit an ELT value or a SPEC value described below. The computing interval used on the present step is available in CHSUB as the algebraic difference between CUVAR (1) and VAR (1). Since the subroutine is used on a binary computer and the interval variation is a halving and doubling process, CI should be a power of 2.

SPEC — A floating-point value supplied by the user which specifies how often he wishes INT1 to return control to the calling program so that the user may print his results.

SPEC = 0.0: Control will be returned after every acceptable integration step.

SPEC > 0.0: SPEC is the absolute value of the specified increment of the independent variable for which the user desires control returned to the calling program.

The first printout is made at the initial value of the independent variable. The next return is at the nonzero integer multiple of SPEC closest to the initial value of the independent variable. The remaining returns occur at values which have been updated from this point by the increment given in SPEC. The return times generated by the increment given in SPEC are not altered by an intervening return due to an ELT value (explained in the section "ELT").

CIMAX — A floating-point value supplied by the user which is the absolute value of the maximum computing interval that will be used. This value will

be used if the doubling process would extend the computing interval to a value larger than CIMAX. CIMAX should be set to 0.0 if there is no desired maximum.

IERR — An integer value supplied by INT1 as an error code. It must be checked at every return to the calling program. It may have the following values:

1 A normal return, no error.

2 The ELT block is not monotonic in the direction of integration.

3 The variables have failed to meet the local-truncation-error requirements nine consecutive times. The answers at the beginning of the interval are still in the VAR array.

4 The variables have failed to meet the local-truncation-error requirements at least nine times over the last three intervals. An acceptable answer has been reached, however, and is in the VAR array.

VAR — A double-precision one-dimensional array containing the independent variable followed by the N dependent variables. The user must store the N+1 initial values (in the double-precision mode) in the array for initialization. INT1 will store the new values of the variables in VAR after each integration step when they are accepted by the user in CHSUB. The elements of the VAR block can be printed out in the calling program in accordance with the user's specification in SPEC.

CUVAR — A double-precision one-dimensional array which is given values by INT1 for two purposes. INT1 will store in the same order as the VAR array the values of the independent variable and N dependent variables at which the derivatives are to be evaluated in the DERSUB subroutine. Although CUVAR must be in a double-precision array in INT1 to maintain the "partial double-precision mode" of computation, the evaluation of the derivatives should be in single precision. Two suggested ways of doing this are as follows: (1) Consider CUVAR as a single precision array of 2(N+1) elements in the DERSUB subroutine and when using the ith element in a computation, assign to it the subscript value (2i-1), and (2) at the beginning of the DERSUB subroutine, transfer from CUVAR to some newly defined single-precision array and evaluate the derivatives using the latter.

INT1 will also store the tentative answers after each integration in the CUVAR array before calling CHSUB so that the user can check these

values to decide to accept or reject the answers. If accepted, the CUVAR values will then be transferred to the VAR array. The decision as to whether the computation in the CHSUB subroutine should be done in single or double precision is a function of the individual application. In most cases single precision is adequate and can be accomplished by applying suggestions (1) and (2) on the preceding page to the VAR and CUVAR arrays.

No values need to be initially stored in CUVAR.

DER — An N+1 single-precision array in which the user will store the derivatives evaluated in DERSUB. The derivatives should be arranged by the user in DERSUB in the same order as the VAR block so that DER (2) will be the derivative of the variable stored in VAR (2), for example. DER (1) will be unused. The derivatives must be computed using values of the variables which have been stored in CUVAR (not VAR) by INT1. To avoid unnecessary double-precision computation, the user should apply the suggestion described under CUVAR.

ELE1 — A one-dimensional array of N values supplied by the user each of which is the upper bound of local relative truncation error for the respective dependent variables. If the error for any variable exceeds its respective ELE1 value, the computing interval is halved and the integration restarted at the beginning of the present interval. If the error for all the variables is less than 1/128 of their respective ELE1 values, the computing interval is doubled for the next integration step.

ELE2 — A one-dimensional array of N values supplied by the user which represents a small value or "relative zero" for the respective dependent variables. If the absolute value of any of the variables is less than its respective ELE2 value, the relative error criteria for that variable will not be applied.

ELT — A one-dimensional array of NT values supplied by the user which are values of the independent variable at which the user specifically desires control returned to his program. The values in the ELT block must be monotonic in the direction of integration, or an error return will be given by INT1.

ERRVAL — A one-dimensional array of N elements in which INT1 stores an estimate of the local truncation error for each of the N dependent variables. The relative errors are computed from these values and compared with the specified ELE1 values.

DERSUB — The name of a subroutine written by the user which will be called by INT1 to evaluate the derivatives. The derivatives must be stored in the DER array. INT1 will call DERSUB to evaluate the derivatives with the values of the variable it has stored in the CUVAR array.

These evaluations should be done with the use of single-precision arithmetic. The name given to the DERSUB subroutine must appear in an EXTERNAL statement in the calling program. The user may return to the calling program by storing a 4 in II.

CHSUB — The name of a subroutine written by the user to allow certain logical control. After each integration step, INT1 will make available to the user in CHSUB the tentative answers in the CUVAR array. The VAR array will contain the last accepted answer (that is, the value of the variables at the beginning of the interval). Whenever the user specifies that the answers are acceptable, the values in the CUVAR block are transferred to the VAR block. In CHSUB the DER block will contain the values of the derivatives evaluated with the present CUVAR block. The user has three options:

(1) Not change II. In INT1, II = 1 denotes that the user has accepted the answers in the CUVAR block. Upon entry to CHSUB from INT1, II always equals 1.

(2) Set II = 2. The user does not accept the answers and wishes to recompute the interval using a new computing interval which he stores in CI. This computing interval must be smaller than the computing interval just used. This new value of CI will now be stored by INT1 as the normal computing interval for the subsequent integration steps.

(3) Set II = 3. The user accepts the answer but wishes to denote a condition that he can test in the calling program. Control will be returned to the calling program with the answers in the CUVAR array transferred to the VAR array.

The name given to the CHSUB subroutine must appear in an EXTERNAL statement in the calling program.

ITEXT — An integer code word supplied by the user which gives him the option to have INT1 print out a time history of the computing interval and the reasons for its variation. This printout should be requested only for problems which must be rerun because of unsatisfactory results the first time.

ITEXT = 0: No printout is requested.

ITEXT = 1: A printout is requested.

Restrictions: See arguments listed under CALL statement.

Method: INT1 is a fifth-order integration subroutine. The classical fourth-order Runge-Kutta formula is applied in conjunction with Richardson's "extrapolation to the limit" theory. INT1 is a variable-interval-size routine in which the interval is varied to meet a specified local relative truncation error.

Accuracy: The variable-interval-size mode of logic is used to make available an estimate of the local relative truncation error which is then controlled as explained in the ELE1 block discussion.

Roundoff error is controlled by use of the "partial double-precision mode of computation" as explained in reference (a) of this subroutine.

Reference: (a) Henrici, Peter: Discrete Variable Methods in Ordinary Differential Equations. John Wiley & Sons, Inc., c.1962.

Storage: 2703_8 locations

Subroutine date: August 1, 1968

REFERENCES

1. Garrett, L. Bernard; Suttles, John T.; and Perkins, John N. (with appendix C by G. Louis Smith and L. Bernard Garrett): A Modified Method of Integral Relations Approach to the Blunt-Body Equilibrium Air Flow Field, Including Comparisons With Inverse Solutions. NASA TN D-5434, 1969.

2. Scarborough, James B.: Numerical Mathematical Analysis. Fifth ed., Johns Hopkins Press, 1962.

NASA-Langley, 1970 — 1 L-7071

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

OFFICIAL BUSINESS

FIRST CLASS MAIL

POSTAGE AND FEES PAI
NATIONAL AERONAUTICS
SPACE ADMINISTRATION

POSTMASTER: If Undeliverable (Section 1
Postal Manual) Do Not Re

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546